NUTRACEUTICAL TORTILLAS AND TORTILLA CHIPS PREPARED WITH BRAN FROM SPECIALTY SORGHUMS

A Thesis

by

GUISSELLE CEDILLO SEBASTIAN

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

December 2005

Major Subject: Food Science and Technology

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Approved by:

Chair of Committee,	Lloyd W. Rooney
Committee Members,	Ralph D. Waniska
	Luis Cisneros-Zevallos
Chair of Food Science and Technology Faculty,	Rhonda K. Miller

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ABSTRACT

Nutraceutical Tortillas and Tortilla Chips Prepared with Bran
from Specialty Sorghums. (December 2005)
Guisselle Cedillo Sebastian, B.S., Insituto Tecnologico y de
Estudios Superiores de Monterrey
Chair of Advisory Committee: Dr. Lloyd W. Rooney

The effects of sorghum bran addition on table tortillas and tortilla chip properties were evaluated. Texture, phenol content, antioxidant activity, and sensory characteristics were evaluated. Texture was measured by objective and subjective tests. Products were analyzed for phenols following the Folin-Ciocalteu procedure and for antioxidant potential following the ABTS (2,2'-azinobis (3-ethylbenzothiazoline-6-sulfonic acid) method. Sensory properties were evaluated using a nine point hedonic scale.

Bran from two specialty sorghums: sumac (high tannin) and black (high anthocyanins) was added at 0, 5, and 10% to table tortillas and tortilla chips. For table tortillas the interaction of sorghum bran with an antistaling formula containing guar gum, carboxymethylcellulose and maltogenic alpha-amylase was assessed.

Tortillas containing sorghum bran had a more friable structure than the control. This detrimental effect was overcome by the antistaling formula. Additives made fluffier tortillas with improved texture and appearance. Tortillas containing sorghum bran and the antistaling formula were acceptable to panelists. At 5% sorghum bran inclusion, there was no significant difference in sensory attributes from the control aside from appearance. Tortillas containing sorghum bran had a dark natural color comparable to that of blue corn tortillas.

Tortilla chip texture was not significantly affected by addition of bran to the formula. As in table tortillas, addition of sorghum bran produced minor changes in the texture and flavor of the product, but a significant change in appearance acceptability. Tortilla chips had a dark color, comparable to the one of blue corn tortilla chips.

Sumac bran yielded larger amounts of phenols and antioxidant activity than black bran. Levels of phenols and antioxidant potential increased with increased bran. Although processing caused a measurable loss of sorghum bran antioxidants, table tortilla and tortilla chips were still a significant source of phenols and antioxidant activity.

The addition of sorghum bran produced tortillas and tortilla chips with increased levels of dietary fiber and antioxidants, without adversely affecting other sensory properties.

DEDICATION

To my family and friends for all their love, encouragement and support.

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INTRODUCTION

Antioxidant compounds have received increased attention for their potential to provide protective effects against chronic and degenerative diseases, such as cancer and cardiovascular disease. They have the ability to scavenge free radicals in the human body and thereby decrease the extent of free radical damage to biological molecules like lipids, proteins and DNA (Wu et al. 2004).

Antioxidants are found in commonly consumed foods, particularly in fruits and vegetables. The most familiar antioxidants are vitamins A, C, and E, but recently the ability of other non-nutrient compounds like phenols to serve as antioxidants has been recognized (Hagerman et al. 1998).

Some sorghum grains such as Sumac and Black have high levels of antioxidants that can be concentrated by milling. Decortication has been utilized to produce brans with antioxidant activities that exceed that of blueberries, strawberries, and red wine on a dry weight basis (Awika 2003). Specialty sorghum brans are a promising nutraceutical ingredient rich in phytochemicals and fiber.

Bran from specialty sorghums has been used to produce foods with acceptable properties, such as cookies bread, and extrudates (Mitre-Dieste et al. 2000; Gordon 2001; Rudiger 2003). Awika (2003) found that bread and cookies containing tannin sorghum bran retained approximately 60 and 78% of the bran antioxidant activity after processing.

Sorghum bran is an ingredient with intrinsic healthfulness that could be used to produce nutraceutical tortillas. Tortilla is a flexible product that can be used in a variety of ways and is consumed widely and consistently; thus, tortilla represents an excellent vehicle for antioxidant delivery to consumers.

With the growing interest in wellness and nutritionally enhanced foods, corn tortillas and tortilla chips containing sorghum bran could represent an excellent alternative for health-conscious consumers. Besides being a source of nutraceutical compounds, sorghum bran naturally gives the product a dark color, a characteristic usually associated with healthy foods.

This thesis follows the style and format of Cereal Chemistry.

This study aims to elaborate and characterize table tortillas and tortilla chips containing 0, 5, and 10% bran from specialty sorghums (Sumac and Black).

Specific objectives are:

1. To produce corn tortillas and tortilla chips containing 0, 5 and 10% bran from Sumac and Black sorghums.
2. To evaluate the effect of bran addition on the physical, chemical and antioxidant properties of table tortillas and tortilla chips.
3. To assess the effect of an antistaling formula containing guar gum, carboxymethylcellulose (CMC) and maltogenic α-amylase on tortillas containing sorghum bran.

LITERATURE REVIEW

Functional foods

Americans are moving towards treating their health problems by using functional foods. About 93% of consumers believe that some foods have health benefits that go beyond nutrition, and contain natural components that can help prevent and even cure disease (IFIC 2002; FMI 2002). The Shopping for Health 2002 study reveals that 90% of respondents feel that eating healthy is a better way to manage illness than medication. Recently health has been challenging convenience as the most important new food product attribute (Sloan 2004).

According to Packaged Facts (2003) the sales of functional foods and beverages reached $22.8 billion in 2002, an increase of 13.9% from 2001 sales, and the market is still expected to grow until 2007. Despite the wide array of fortified products available in the market, consumers still feel that their diet is deficient in soy protein (34%), fiber (31%), omega-3 fatty acids (31%), soy isoflavones (31%), whole grains (28%), and antioxidants (27%), among others (NMI 2003). Hence, a product delivering antioxidants and fiber has the potential to be attractive to consumer seeking alternative ways to incorporate those compounds in their diet.

Tortilla market

Tortillas represent a promising vehicle for delivering phytochemicals to consumers due to their wide and growing consumption. Tortillas are the second most popular bread type in America, and are responsible for 32% of the sales for the U.S. bread industry, just behind white bread (34%) (TIA 2003). Furthermore, sales of white bread have decreased while tortilla sales have increased in recent years. Tortillas could surpass white bread as the top-selling bread in the U.S. by the end of this decade (Market Watch 2004). The increasing percentage of Hispanics, who are expected to become the largest minority in the U.S., and product versatility are the two main factors driving the increase in tortilla popularity (Molvany 2004). Tortilla sales reached $4.5 billion dollars in 2002, and are expected to reach $5 billion by 2004 (TIA 2003).

Among health issues having an impact on the tortilla industry, the low-carb trend and the demand for organic products are the main concerns. Despite the popularity of the Atkins and South Beach diets, tortilla producers have not been as negatively affected as the bread industry (Malovany 2004). Tortillas and tortilla chips containing sorghum bran will have a lower amount of digestible carbohydrates than their regular counterparts and could be targeted to consumers influenced by those trends.

Snack markets

Americans consume four or more snacks a day and more than 6.5 billion pounds of snack food annually (Mintel International Group 2004). Packaged Facts (2004) estimates that U.S. retail sales of snack foods totaled $47.1 billion in 2003, 4% over 2002 sales. The salty snack category, 41% of the snack foods market, grew 23% from 1998 to 2003 (Mintel International Group 2004). Market growth is driven by convenience, flavor trends, and diet and health concerns (Mintel International Group 2004, Packaged Facts 2004).

Two-thirds of Americans consider snacking to be part of a healthy diet (NMI, 2003). Salty snacks that are organic, natural, low in calories, fat, carbohydrates, and sodium, or offer other health-promoting benefits have greater demand (Mintel International Group 2004, Packaged Facts 2004). Moreover, around 34% of new salty snack products introduced in 2003 featured some type of health positioning (Mintel International Group 2004). Since tortilla chips containing sorghum bran would have lower amounts of digestible carbohydrates and would be rich in antioxidants, they represent a healthier alternative to regular tortilla chips.

Antioxidant properties of sorghum phenols

Sorghum fractions have high in vitro antioxidant activity and may offer health benefits commonly associated with fruits (Awika et al., 2003). Awika (2003) found that phenol content correlates strongly with antioxidant activity measured by various methods, which suggests that phenols are largely responsible for the activity. Flavonoids such as catechins, proanthocyanidins (tannins), and anthocyanins are the most abundant phenolic compounds, depending on the sorghum type and variety (Awika 2000).

Tannins

Tannins are water-soluble phenolic compounds with molecular weights between 500 and 3,000 Daltons, and are classified into two categories: hydrolyzable and nonhydrolyzable or condensed tannins. Condensed tannins are mainly the polymerized products of flavan-3-ols and flavan-3, 4-diols, or a mixture of the two. Condensed tannins are widely distributed in fruits, vegetables, red wine, and food grains, such as sorghum, finger millets, and legumes (Chung et al. 1998). In sorghum, tannins are located in a thick layer called the testa, which is located just beneath the pericarp. Type III brown sorghums have a thick pigmented testa rich in tannins, and dominate all other sorghum types in total phenols, tannins, and antioxidant activity (Awika 2003).

Tannins often decrease feed efficiency and protein digestibility in experimental feeding trials. Therefore, foods rich in tannins have historically been considered nutritionally undesirable (Chung et al. 1998). Nevertheless, the ability of tannins to serve as antioxidants has recently been recognized (Hagerman et. al 1998).

Tannins have shown beneficial anticarcinogenic, antimutagenic, and antimicrobial properties that may be related to their antioxidant characteristics, which are important in protecting cells from oxidative damage (Chung et al. 1998). Hagerman et al. (1998) found that tannins are 15-30 times more effective at quenching peroxyl radicals than simple phenolics or Trolox. They attributed this ability to the high molecular weight of tannins and to the proximity of their aromatic rings and hydroxyl groups.

Anthocyanins

Anthocyanins are water-soluble pigments responsible for the bright red, blue and violet colors of fruits and other foods (Mazza and Miniati 1994). They have anti-inflammatory (Lietti et al. 1976), anti-cancer, and chemo-protective properties (Karaivanova et al. 1990), are vasoprotective (Lietti et al. 1976), and delay the onset of diabetes (Karaivanova et al. 1990). In sorghum, the most common anthocyanins are the 3-deoxyanthocyanidins (Gous, 1989), which include apigeninidin and luteolinidin. These anthocyanins are relatively rare and are distinct in that they lack a hydroxyl group at the C-3 position and exist in nature substantially as aglycones (Clifford, 2000). Black sorghum varieties are the highest in anthocyanin pigments, followed by brown and red sorghum varieties (Awika 2000). Awika et al. (2003) reported that the antioxidant capacity of black sorghums and their brans correlated strongly (R^2=0.94) with their anthocyanin contents, and concluded that anthocyanins contributed significantly to any potential health benefits of black sorghum.

Effects of thermal processing on the stability of sorghum antioxidants

Awika (2003) reported that brown sorghum bran in bread and cookies, retained 60 and 78% of the original bran antioxidant activity respectively, after processing. High tannin sorghum extrudates retained 21% of their original assayable tannin content, and 89% of their original antioxidant activity (Awika 2003). Processing structurally alters tannins, without significantly hindering antioxidant potential. Reduction of detectable tannins in thermal processing was attributed to structural break down and chemical rearrangement. In addition, interaction with proteins and carbohydrates may lower activity due to reduced solubility.

Regarding the thermal processing of black sorghums, Awika (2003) found that bread and cookies fortified with black sorghum bran, retained about 57 and 72% of the original antioxidant activity, respectively. Extrudates from black sorghum retained 52% of their anthocyanin contents and 75% of the original antioxidant activity (Awika 2003).

Tortillas and tortilla chips made from specialty sorghums

The potential of specialty sorghums to produce dark color tortillas and tortilla chips rich in phenolic compounds, has been previously evaluated (Zelaya-Montes 2001). White, brown and black sorghums were processed into tortillas and tortilla chips. The effects of varying pH (7, 9 and 11) and sorghum type on tortilla and tortilla chip properties were evaluated. A darker pericarp color and higher pH produced darker tortillas and tortilla chips. Phenols were mostly retained during tortilla and tortilla chip processing. Products containing black and brown sorghum were significantly higher in phenols than the ones containing white sorghum. In a sensory evaluation, the overall acceptability of the sorghum tortilla chips was relatively low. White sorghum tortilla chips (pH 9) were more acceptable (70%), followed by brown sorghum chips at pH 9 (68%), and brown sorghum chips at pH 11 (59%). Black chips were not favored in overall acceptability.

The ability of sorghum grains to produce dark colored products relies on the presence of pigments located in the outer layers of the kernel. These compounds can be concentrated 3-7 fold in the bran fraction through decortication (Awika 2000). The use of just the bran fraction, instead of the whole kernel, and nixtamalized corn flour could produce dark colored tortillas and tortilla chips that are still rich in phenolic compounds and antioxidant activity, but are more acceptable to consumers.

Fiber fortification

The American Dietetics Association (ADA) recommends that adults consume 20-35 g of dietary fiber per day. Although dietary fiber has been shown to aid in cardiovascular health, gastrointestinal health, cancer prevention, and weight management, the average American consumes only 12 -17 g per day (Ohr 2004).

There are few documented attempts to fortify corn tortillas with fiber. Mitre-Dieste (2001) substituted barley flours for nixtamalized corn flour (NCF) at 10-25%. The addition of barley flour increased the dietary fiber content and improved tortilla extensibility without affecting the color, but a slight off-flavor was reported.

Nixtamalized corn hulls, a sub product from the nixtamalized corn flour industry, have been used as a fiber source in tortillas. Nixtamalized corn hulls were substituted for NCF at 20, 25, and 30%. Although substitution up to 25% yielded acceptable products to consumers, as the level of substitution increased tortilla rollability decreased (Soto-Mendivil and Vidal-Quintanar 2001). On the contrary, Guajardo-Flores (1998) reported that either pericarp from nixtamal or alkaline treated corn bran, and alkaline pH improved tortilla texture.

In snack applications, resistant starches have been used to produce fiber-fortified products. Besides increasing the fiber content, they are reported to increase expansion of extruded and baked snacks, to reduce oil absorption in fried snacks, and to reduce cracking and breakage (Huang 1995, 2001).

Sorghum bran is a good source of insoluble fiber that could be used to increase tortilla dietary fiber content. Specialty sorghum brans have the potential produce dark colored table tortillas and tortilla chips with increased fiber content and improved antioxidant activity. The impact of bran addition on product properties needs to be assessed.

MATERIALS AND METHODS

Sorghum characterization

Test weight was determined with a Winchester Bushel Meter. Density was evaluated using a gas comparison pycnometer (Multipycnometer, Quantachrome, Syosset, NY). Thousand kernel weight (TKW) was determined by weighing 100 kernels and multiplying by ten. Hardness was evaluated with a tangential abrasive dehulling device (TADD) with 20 g sample and 3.5 min abrasion time. A single kernel hardness tester (SKHT, model SKCS 4100, Perten Instruments, Reno, NV) was also utilized to determine hardness. Grain color was determined with a colorimeter (model CR-310, Minolta C0., LTD. Ramsey, NJ). Color was recorded using the CIE-L* a* b* uniform color space (CIE-Lab), where L* indicates lightness, a* indicates hue on a green (-) to red (+) axis, and b* indicates hue on a blue (-) to yellow (+) axis. Protein and fat contents were measured using an NIR 6500 spectrophotometer following Approved Method 39-21 (AACC 2000). Dietary fiber was determined following standard analytical procedures (AACC 32-05).

Raw materials

Nixtamalized corn flour (NCF)

Nixtamalized corn flour (NCF), Tortilla # 4 without additives (Minsa, Muleshoe, TX, USA) was used to prepare the table tortillas. NCF, Tortilla Chip # 1 without additives (Minsa, Muleshhoe, TX, USA), was used to prepare the tortilla chips.

Sorghum bran

Bran from Sumac (Type III sorghum) and Black Tx430 sorghums grown in College Station, TX in 2001 was used. The grain was decorticated in 4 kg batches in a PRL dehuller (Nutana Machine Co., Saskatoon, Canada) to obtain percent removals that corresponded to the highest concentration of tannins and phenols (12% and 15% for Sumac and Black respectively) (Awika 2000). The decorticated grain was cleaned through a KICE grain cleaner (Model 6DT4-1, KICE Industries Inc., Wichita, KS). After collecting the bran, it was milled in a pin mill to reduce particle size. The ground samples were sieved using N0. 40, 60, 70, 80 and 100 U.S. standard sieves to determine particle size distribution. Dietary fiber was determined following standard analytical procedures (AACC 32-05). Bran color was determined with a colorimeter (model CR-310, Minolta C0., LTD. Ramsey, NJ), using the CIE-L* a* b* uniform color space (CIE-Lab).

Sodium carboxymethylcellulose (CMC)

Ticalose CMC 2500 (TIC Gums, Belcamp, MD, USA) with degree of substitution in the range of 0.65-0.90, pH of 6.5-8.5, sodium fraction of 7-8.9% and a medium viscosity (~2,500 cps at a concentration of 1%) was used.

Guar gum

Guar gum BLN-200-HV (TIC Gums, Belcamp, MD, USA) was used. This hydrocolloid forms a weak gel in the presence of water and has a medium viscosity (~3,500 cps at a concentration of 1%).

Preservatives

A combination of potassium sorbate (0.5% db) and fumaric acid (0.4% db) was used to delay microbial spoilage.

Maltogenic α-amylase

Alpha-amylase from *Bacilus subtilis* (Innovative Cereal Systems, Wilsonville, OR, USA) with an activity of 10,000 units/g was utilized. One enzyme unit (maltogenic alpha-amylase unit, MAU) is defined as the amount of enzyme, which under standard assay conditions cleaved 1 μmol of maltotriose per min.

Tortilla and tortilla chip preparation

Tortilla standard baking procedures

One kg of nixtamalized corn flour (NCF), sorghum bran, and additives (when required) were mixed for 5 min at low speed with a paddle using a 20 qt mixer (Model A-200, Hobart, Troy, OH, USA). The dry ingredients were then mixed with distilled water in a ratio of 1:1.2 (NCF: water) for table tortillas, and 1:1.1 for tortilla chips. They were mixed with a hook for 30 s at low speed and 90 s at medium speed. An additional gram of water, for every gram of sorghum bran was added.

Preservatives (0.5% fumaric acid and 0.4% potassium sorbate, db) were utilized in table tortillas, but not in tortilla chips. Only table tortillas with the antistaling formula contained CMC, guar gum and maltogenic alpha-amylase.

Masa was placed in a polyethylene bag and equilibrated for 10 min. After equilibration the masa was mechanically sheeted and die cut into 15 cm diameter disks weighing about 30 g for table tortillas and about 28 g for tortilla chips. A sheeter/former

(Model CH4-STM, Superior Food Machinery, Inc., Pico Rivera, CA, USA) was used in this step. Tortillas were baked for 60 s in a gas-fired three-tier oven (320^{o}C top, 280^{o}C middle and 250^{o}C bottom) (Model C-0440, Superior Food Machinery, Pico Rivera, CA, USA), cooled and stored in polyethylene bags. Table tortillas were stored at refrigeration temperatures (4^{o}C) for up to four days.

Frying

Tortillas for tortilla chip production were cut in round pieces (½ in mm diameter) and then deep fat fried (Frymaster Products Model MJ-35, Shreveport, LA) at 180^{o}C for 60 s in frying oil. Tortilla chips were drained, cooled, and stored in polyethylene bags.

Analytical procedures

Moisture

Moisture was evaluated the day of processing. The one-stage moisture oven AACC method 44-15A (AACC 2000) was used. It consists of drying a sample in a forced air oven (model 16, Precision Scientific, Chicago, IL) for 24 hr at 130^{o}C. Moisture was calculated by weight lost.

pH

Tortilla pH was measured within 1 hr after baking. A pH meter (model 10, Beckman Instruments, Fullerton, CA) was used to conduct the measurements. Ten grams of tortillas were ground using a coffee grinder and mixed with 90 ml of distilled water. The electrode probe (Corning "3 in 1", Corning, Inc., New York, NY) was dipped in the water-tortilla solution and the pH recorded.

Color

Table tortillas and tortilla chips were evaluated for color using a colorimeter (Model CR-310 Minolta Co., LTD. Ramsey, NJ). For table tortillas the measuring head was placed into the center of each tortilla, whereas for the chips, four whole chips were randomly selected from each sample and placed in the granular materials attachment for color evaluation. Color values were measured in triplicate and recorded as averaged L^*= lightness (0=black, 100=white), a^* ($-a^*$=greenness, $+a^*$=redness) and b^* ($-b^*$=blueness, $+b^*$=yellowness).

Oil content

The oil content of the chips was determined following the AOAC Soxhlet extraction procedure.

Phenol content

Extraction was performed as described by Awika et al. (2003), using 1% HCl in methanol as solvent. Tortilla samples were dried in a forced air convection oven at 60°C for 12 h and ground through a cyclotec mill (UDY Corp., Fort Collins, CO) (1 mm mesh screen) prior to extraction. Tortilla chips were defatted before being extracted with acidified methanol. To remove the oil, three grams of ground tortilla chip sample were extracted with 25 ml of petroleum ether with shaking for one hour. After extraction the supernatant was decanted. Extraction was repeated two more times. After the third extraction the sample residue was poured on a filter paper and placed under a hood to allow residual ether to evaporate. Once the sample residue was dried, it was sifted through US sieve No. 35. The material that remained over the sieve was reground using mortar and pestle.

Awika's (2003) modification of the Folin-Ciocalteu method of Kaluza et al. (1980) was used to determine phenols. The sample extract (0.1 mL) was reacted with 0.4 mL Folin-Ciocalteu reagent and 0.5 M ethanolamine for 20 min at room temperature. Absorbance was then measured using a UV/VIS spectrophotometer (Cary 300 Bio, Varian Co., Walnut Creek, Ca) at 600 nm.

Antioxidant activity: ABTS [2,2´- azinobis (3-ethyl-benzothiaziline-6-sulfonic acid)]

Samples were analyzed for antioxidant activity with the ABTS methodology. The extraction was performed following the same procedures utilized for phenol content determination. The assay was executed following the procedure described by Awika et al. (2003). $ABTS^{\cdot+}$ was generated by reacting 3 mM of $K_2S_2O_8$ with 8 mM ABTS salt in distilled water for 16 h at room temperature in the dark. The $ABTS^{\cdot+}$ solution was diluted with pH 7.4 phosphate buffer solution containing 150 mM NaCl (PBS) to obtain an initial absorbance of 1.5 at 730 nm. Samples and standards (100 μm) were then reacted with the $ABTS^{\cdot+}$ solution (290 μm) for 30 min. Trolox was used as a standard.

Texture evaluation of tortillas

Subjective pliability of tortillas, was used to monitor the cracking and breaking of a tortilla as a result of staling. A tortilla was evaluated by squeezing it inside the palm of one hand, holding it for 2 s, and then releasing it. How well it held together was evaluated using a five-point scale, defined as 1 = complete crumbling, 2 = almost total crumbling, 3 = a lot of cracking, no crumbling, 4 = isolated cracks and 5 = completely pliable (no cracks).

Subjective rollability of tortillas, which evaluates the cracking and breakage of a tortilla when rolled, was evaluated. Half of a tortilla was rolled around a 1.0 cm dowel. A score on a 1 to 5 scale, where 1 = unrollable and 5 = rolls without cracking or breaking, was given.

The one-dimension extensibility test was conducted using a texture analyzer (TA.XT2, Texture Technologies Corp., Scarsdale, NY/Stable Micro Systems, Godalming, Surrey, UK), following the method of Suhendro et al. (1999). In this test a tortilla strip (70x35 mm) held between two clamps was pulled upward until the tortilla broke apart. Rupture force (N) and modulus of deformation (N/mm) were recorded.

Texture evaluation of tortilla chips

Chip texture was evaluated using a texture analyzer (TA.XT2, Texture Technologies Corp., Scarsdale, NY/Stable Micro Systems, Godalming, Surrey, UK) with a ball probe (0.25 in), following Zelaya-Montes (2001) procedures. Maximum force and area under the force versus distance curve (work required to break the chip) was measured on 30 chips.

Breakage susceptibility of chips was evaluated by a tumbler technique (Quintero-Fuentes et al. 1999). Ten chips were weighed and placed inside rigid plastic bottles containing one 3.8-cm diameter rubber ball. Bottles were attached to a tumbler that rotated for 1 min at 37.4 rpm. The number and weight of broken pieces of different sizes were recorded.

Sensory evaluation

Thirty untrained panelist evaluated tortilla and tortilla chips for appearance, texture and flavor. The products were rated using a nine-point hedonic scale where 9= like extremely, 5= neither like nor dislike, and 1= dislike extremely. Different panelists evaluated tortilla and tortilla chip samples during different sessions.

Statistical analysis

Analysis of variance (ANOVA) was performed using SPSS v11.5 for Windows (SPSS Inc.). Differences were analyzed with Duncan's test. A confidence level of 95% was used.

RESULTS AND DISCUSSIONS

Sorghum characterization

The physical properties of the two sorghum varieties utilized for sorghum bran production are shown in Table I. As indicated by the diameter measurement, Sumac had a smaller kernel size than Black sorghum. The difference in kernel size was also reflected by the thousand-kernel weight, where Sumac had less than half the value of Black sorghum. Sumac sorghum was softer than Black sorghum as measured by the single kernel characterization system (Table I), but the opposite was found with the abrasive procedure (TADD). This is contradictory, since hard sorghum samples are generally more resistant to material removal (Awika et al. 2005). On the other hand, Black sorghum has a thick pericarp that tends to come off at the initial stages of decortication, and this behavior could explain the large amount of material removed during the test. Black sorghum was denser than Sumac sorghum. In general grain hardness is positively related to grain density. Dense kernels have higher hardness values because the endosperm is more tightly organized.

Kernel appearance was different (Fig I). Sumac had a reddish-brown color, whereas black sorghum had a dark purple color. Objective color measurements are shown in Table II. L* values were similar for both sorghum samples, but differences where present for a* and b* parameters. Sumac grain had higher values for the red and yellow hue. Aside from protein, both sorghum grains were similar in composition (Table III). It is likely that protein content varied due to different agronomic and environmental growing conditions. In terms of dietary fiber content Black sorghum grains had a slightly higher value than Sumac grains.

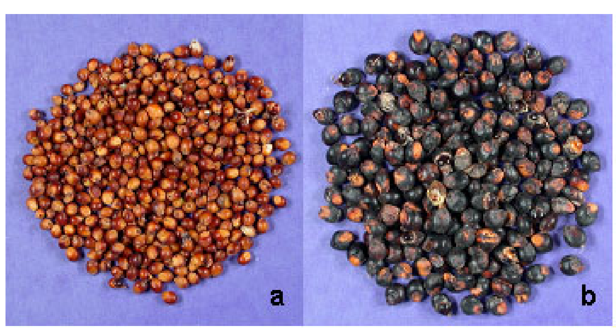

Figure 1. Sorghum grains. a) Sumac, b) Black.

Table I. Physical properties of sorghum grains. Values are means of two observations.

Sample	TKW [1] (g)	Test wt. (Kg/hL)	Density (g/cc)	Hardness (% Removal)	SKH [2]	Kernel Diameter (mm)
Sumac	15.5	78.1	1.3	20.7	64.3	1.9
Black	38.9	75.1	1.5	24.4	72.1	2.7

[1] Thousand-kernel weight

[2] Single kernel hardness

Table II. Color of sorghum grains, where L* indicates lightness, a* indicates hue on a green (-) to red (+) axis, and b* indicates hue on a blue (-) to yellow (+) axis. Values are means of two observations.

Sample	L*	a*	b*
Sumac	36.9	9.4	8.4
Black	35.4	4.9	4.4

Table III. Composition of sorghum grains (% d. b.)

Sample	Protein [1]	Starch [1]	Total DF
Sumac	12.4	70.5	10.2
Black	14.3	71.0	11.4

[1] Measured using NIR 6500, NIR Systems Inc., Springfield, Maryland

[2] Total dietary fiber (AACC Approved Method 32-05)

Bran characterization

Particle size distribution

Although the bran from both sorghum varieties (Sumac and Black) was obtained following the same procedure, Sumac bran was finer than Black bran (Table IV). About 90% of Sumac bran went through the U.S. standard sieve number 100, whereas the majority of Black bran particles were retained above that sieve. Results are consistent with Gordon (2001) who observed that Brown sorghum bran consisted of small particles with round edges whereas Black sorghum bran was composed of relatively large particles with sharp edges.

Differences in particle size distribution are likely due to different milling properties of the grain. Awika et al. (2005) reported differences in decortication behavior among Brown and Black sorghums. For Brown sorghums the amount of material removed increased with increased decortication time, whereas for Black sorghum it decreased. According to Awika et al. (2005) Black sorghum has a thick pericarp that is loosely attached to the endosperm and is easily removed in the initial stages of decortication. Differences in milling performance could be attributed to structural differences of the pericarp. The presence of the testa layer in Sumac affected the way in which the pericarp peels from the grain.

Color

Bran from Sumac sorghum had a reddish-brown color whereas Black sorghum bran was almost black (Fig. 2). Objective color measurements are listed in Table V. As with the grains (Table II) Sumac bran was lighter, and had greater values for the red and yellow hue than the Black bran. The relative darkness of black bran was due to the presence of anthocyanins.

Sorghum brans were darker compared with the kernel. An increase in a* and b* parameters was also observed. This was likely due to concentration of pigments in the bran fraction.

Composition

Black sorghum bran had lower protein content than Sumac bran (Table VI). The same trend was observed for the grains (Table III). The amount of crude fat for Sumac bran was almost three times the one for Black bran. Since most of the lipids are concentrated in the germ and aleurone layer, it is likely that a larger percentage of this fraction was present in the Sumac bran.

The Black sorghum bran was higher in dietary fiber than Sumac bran (Table VI). This was expected since Black sorghum grain had higher dietary fiber values than Sumac and the Black bran contained less starch and germ. Sumac bran lower dietary fiber content was probably due to the presence of endosperm material in the bran fraction removed during decortication. Size, shape, structure of kernel, and endosperm hardness are major factors that affect milling quality of sorghum (Munck 1995). Grains with hard texture have pericarps that more cleanly separate from intact endosperm (Rooney and Miller 1982), whereas softer grains tend to break during decortication, giving a higher percentage of endosperm mixed in with the bran fraction (Eggum et al. 1982). Sumac sorghum had a softer texture than Black sorghum; hence a larger amount of peripheral endosperm may have been removed with the bran. Moreover, Black sorghum has a thick pericarp that comes off more easily during decortication, yielding a cleaner separation of the bran fraction and the decorticated kernel (Awika et al. 2005). Differences in the dietary fiber content of Brown and Black sorghum bran were previously reported by Awika (2000). Brown sorghum bran had a dietary fiber content of 36.1% whereas black sorghum bran had 42.9%.

Phenols and ABTS antioxidant activity

Phenol levels and antioxidant activity of the sorghum brans are shown in Table VII. Although the antioxidant potential and phenol content were higher than previously reported values for similar sorghum varieties (Awika 2003), the trend was similar. Differences could be attributed to environmental effects in a new crop year. Fluctuation of sorghum antioxidant activity across several growing seasons was previously documented by Awika (2003).

As expected, the bran from Sumac sorghum was higher in phenols and antioxidant activity due to its high tannin content. Tannins consistently give higher antioxidant activity in vitro than other phenols (Hagerman et al 1998). Anthocyanins are the major extractable phenols from black sorghums; hence they contribute a major portion of the measured antioxidant activity of the Black sorghum bran (Awika et al. 2004).

Table IV. Particle size distribution (% weight) of sorghum bran abrasively removed and pin milled. Values are means of three observations.

US Standard Sieve No.	Bran	
	Black	**Sumac**
40 (415 µm)	4.5	0.4
60 (250 µm)	20.3	1.4
70 (212 µm)	8.2	1.5
80 (180 µm)	8.9	3.2
100 (150 µm)	11.2	2.9
Plate (<150 µm)	47.0	90.6

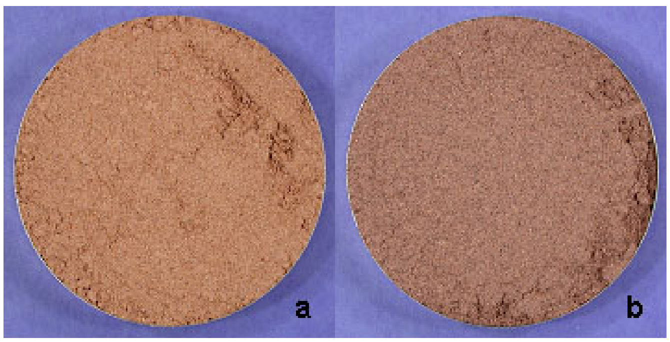

Figure 2. Abrasively removed and pin milled sorghum bran from Sumac (a) and Black (b) sorghum.

Table V. Color of sorghum brans, where L* indicates lightness, a* indicates hue on a green (-) to red (+) axis, and b* indicates hue on a blue (-) to yellow (+) axis. Values are means of two observations.

Sample	L*	a*	b*
Sumac bran	50.5	10.2	11.7
Black bran	44.1	7.5	6.4

Table VI. Sorghum bran composition (%, d. b.)

	Bran Type	
	Sumac	**Black**
Crude Protein	11.8	14.5
Crude Fat	8.0	2.8
Crude Fiber	6.5	10.5
Ash	5.0	4.2
Total Dietary Fiber	38.2	51.7

Table VII. Phenol levels (mg GAE/g) and ABTS antioxidant activity (μmol TE/g) of sorghum brans. Values are means of 3 replicates, 3 observations each. GAE= Gallic acid equivalent, TE= Trolox equivalent.

Bran Type	**Phenols mg GAE/g**	**Antioxidant Activity μmol TE/g**
Black	37.3	505.1
Sumac	90.9	1190.7

Tortillas with sorghum bran

Five treatments were tested: One control, two treatments containing Sumac bran, and two treatments containing Black bran. Formulas are listed in Table VIII.

Physical properties

Moisture content of table tortillas ranged from 46% to 47%. Although the amount of water was adjusted for the formulas containing sorghum bran (one gram of additional water per gram of bran), tortillas with 10% bran still had significantly lower moisture content than the control (Table IX). No significant differences were found in masa moisture content (Appendix A), hence treatments containing 10% sorghum bran lost more water during baking. Even though differences were statistically significant, practical differences were not noticeable.

An increase in pH was observed for tortillas containing sorghum bran (Table IX). Regardless of the amount of bran added, the addition of fumaric acid was fixed to 0.4% nixtamalized corn flour (NCF), thus the increase in pH was likely due to fumaric acid dilution. At the pH observed potassium sorbate is still effective; hence tortilla shelf life was not compromised by the addition of sorghum bran.

Sorghum bran produced naturally colorful tortillas. Black sorghum bran gave dark purple tortillas, whereas Sumac bran yielded reddish-brown tortillas (Figure 3). Color increased as bran addition increased. Objective measurements of color showed that tortillas containing sorghum bran were significantly different from the control (Appendix A). The L* value indicated that as the level of sorghum bran increased, tortilla lightness decreased (Figure 4). The effect was more pronounced for Black bran. Sorghum bran naturally darkened tortillas due to its concentration of proanthocyanidins (tannins) and anthocyanins. Awika (2004) reported that the bran from Black sorghum had significant levels of anthocyanins (4.0-98 mg/g). The a* value (Figure 4) indicated that sorghum bran addition increased tortilla red hue, especially Sumac bran; whereas the b* value showed a reduction in the yellow hue; Black bran had a stronger effect. The naturally occurring dark color caused by sorghum bran could be attractive to health conscious consumers who want a natural looking product; and could give bran from specialty sorghums the potential use as a natural source of color.

Table VIII. Treatment codes and formulation (g)

Treatment	DMF	Water	Sorghum bran		Fumaric Acid	Potassium Sorbate
			Black	Sumac		
Ctrl	1000	1200	-	-	4	5
5Bl	1000	1250	50	-	4	5
10Bl	1000	1300	100	-	4	5
5Su	1000	1250	-	50	4	5
10Su	1000	1300	-	100	4	5

Table IX. Moisture content (%) and pH of tortillas containing sorghum bran. Values are means of 2 replicates, 3 observations each. Means in the same column followed by the same letter are not significantly different (α= 0.05).

Treatment	Moisture (%)	pH
Ctrl	47.4^{b}	5.2^{a}
5Bl	46.9^{b}	5.4^{b}
10Bl	45.8^{a}	5.4^{b}
5Su	47.0^{b}	5.4^{b}
10Su	46.0^{a}	5.5^{b}

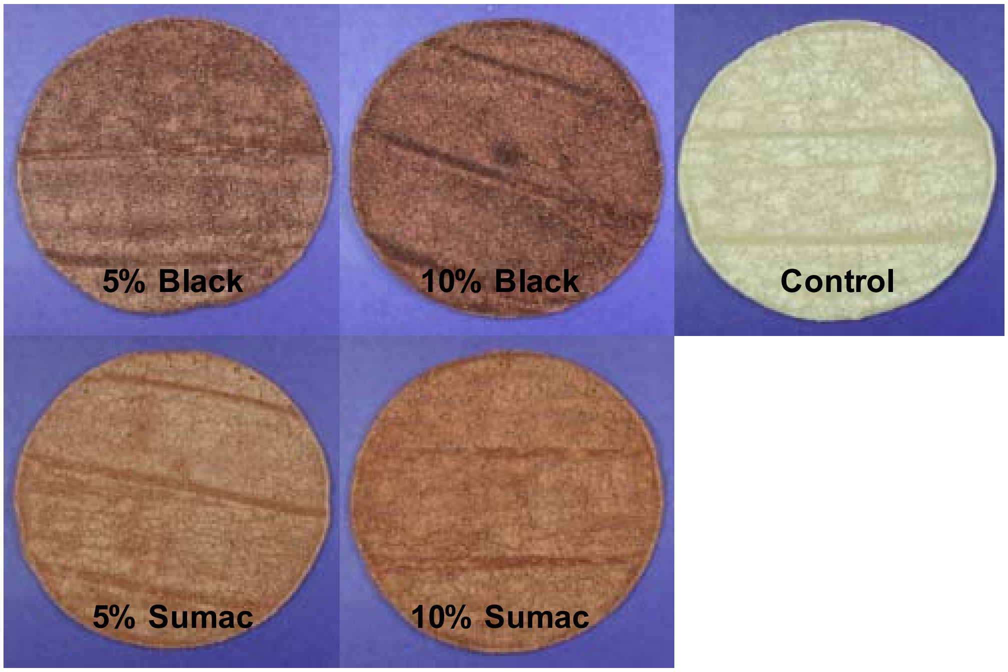

Figure 3. Appearance of tortillas containing sorghum bran and control.

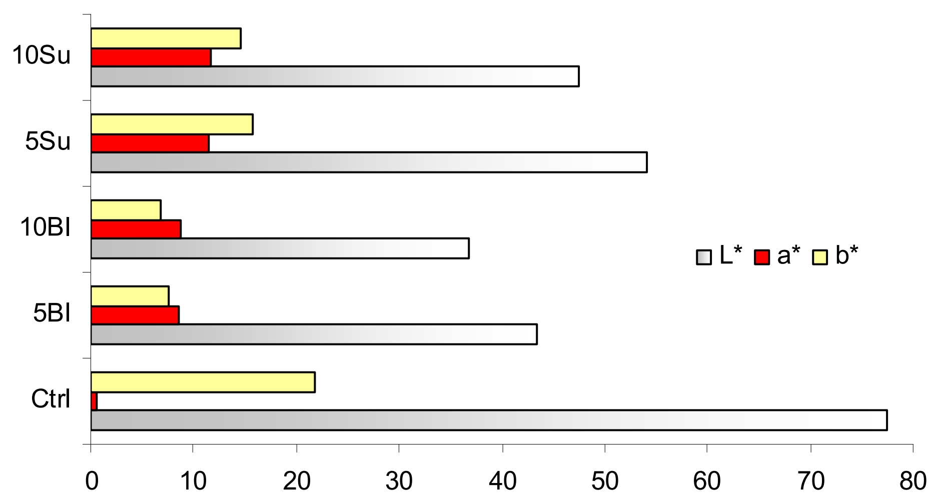

Figure 4. Color of corn tortillas containing sorghum bran, where L* indicates lightness, a* indicates hue on a green (-) to red (+) axis, and b* indicates hue on a blue (-) to yellow (+) axis. Values are means of 2 replicates, 3 observations each. For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, and Su= Sumac bran.

Texture

Results from the 1-D extensibility evaluation are shown in Figures 5, 6 and Appendix A. The force (N) required to break the tortilla, and the modulus of deformation (N/mm), increased through storage time, as tortillas became harder and more brittle. As expected, staling rate was initially higher, and then decreased during storage (Miranda-Lopez 1999).

Upon storage, tortillas containing sorghum bran required lower force to rupture than the control. The bran physically disrupted the continuous matrix that holds tortillas together, making them more susceptible to breakage. The larger particles present in the Black bran are likely responsible for this effect (Table IV). They could easily puncture the tortilla matrix yielding a product more susceptible to breakage. Something similar was previously observed when Black sorghum bran was substituted for 0-30% of wheat flour in a bread formula. Puncturing of air cells in dough by sharp fragments in the Black sorghum bran adversely affected dough structure and significantly reduced bread specific volumes (Gordon 2001).

For the same level of bran addition, Sumac bran produced tortillas with higher rupture force than Black bran (Figure 5). Hence, Sumac bran did not deteriorate tortilla texture as badly as Black bran. After four days of storage there was no significant difference in texture between tortillas containing 5% and 10% sorghum bran. Thus adding an additional 5% of bran did not have any further effect on tortilla texture.

Tortillas containing 10% black sorghum bran had the lowest modulus of deformation. At four days of storage they were the only treatment significantly different from the control (Figure 6, Appendix A). A reduction in the rupture force along with a reduction in the modulus of deformation is associated with tender tortillas (Gutierrez de Velasco 2004). Nevertheless, when the reduction goes beyond a threshold, tortillas are no longer tender; the lack of cohesive structure is such that they become more prone to fall apart with handling.

Tortilla aging decreased rollability and pliability scores (Figures 7 and 8, Appendix A). Black sorghum bran tortillas had less desirable rollability scores than Sumac bran tortillas, which indicate that Black sorghum bran disrupted tortilla structure even more than Sumac bran. These results are consistent with objective texture measurements, specifically with modulus of deformation results, thus modulus of deformation would be the parameter of choice when assessing the effect of sorghum bran addition on tortilla texture.

In general sorghum bran addition had a detrimental effect on tortilla texture. Tortillas were more susceptible to cracking and breakage, especially tortillas containing 10% Black sorghum bran. Differences in particle size among the two sorghum brans, and their effect on tortilla structure are likely responsible for the differences observed in texture.

Microscopy evaluation

Figure 9 show the cross-sectional view of tortillas with and without sorghum bran. Sorghum bran altered tortilla structure by diminishing expansion. Air cell retention and consequently air tunnel formation were reduced by sorghum bran. It is likely that bran particles physically interfered with tortilla matrix formation by puncturing air cells. The effect was more evident as the level of bran increased. These differences in structure are likely responsible for the deterioration in texture observed as a consequence of sorghum bran addition.

At the highest level of bran addition (10%) Black bran tortillas had different structure than tortillas containing Sumac Bran (Fig 9). In Black bran tortillas clusters of large bran pieces where observed, whereas in Sumac bran tortillas, small bran particles randomly distributed were present. Bran clusters interrupted the continuous matrix that holds tortillas together yielding areas more susceptible to cracking and breakage.

Results from the microscopy analysis support the theory that the differences observed in terms of texture were caused by particle size differences. Particle size affected tortilla structure, and differences in structure translated into different texture properties.

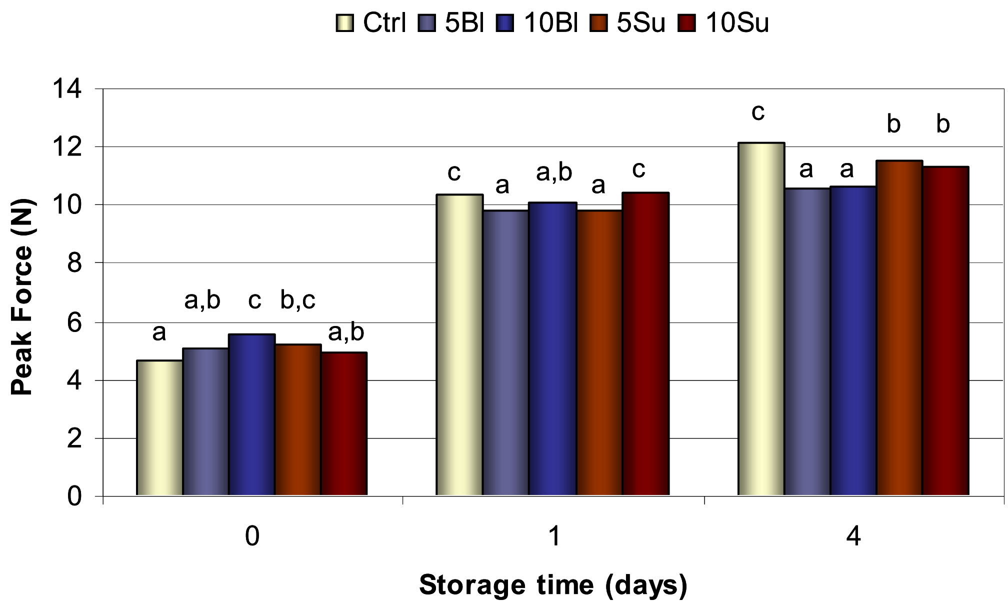

Figure 5. Rupture force (N) of corn tortillas containing sorghum bran stored at 4ºC for up to four days. Values are means of 2 replicates, 10 observations each. Columns with the same letter are not significantly different (α= 0.05). For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, and Su= Sumac bran.

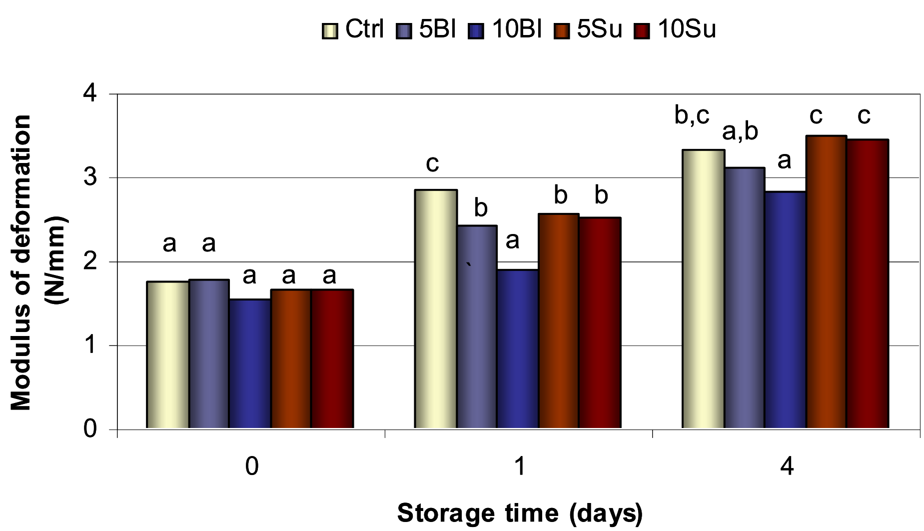

Figure 6. Modulus of deformation (N/mm) of corn tortillas containing sorghum bran stored at 4ºC for up to four days. Values are means of 2 replicates, 10 observations each. Columns with the same letter are not significantly different (α= 0.05). For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, and Su= Sumac bran.

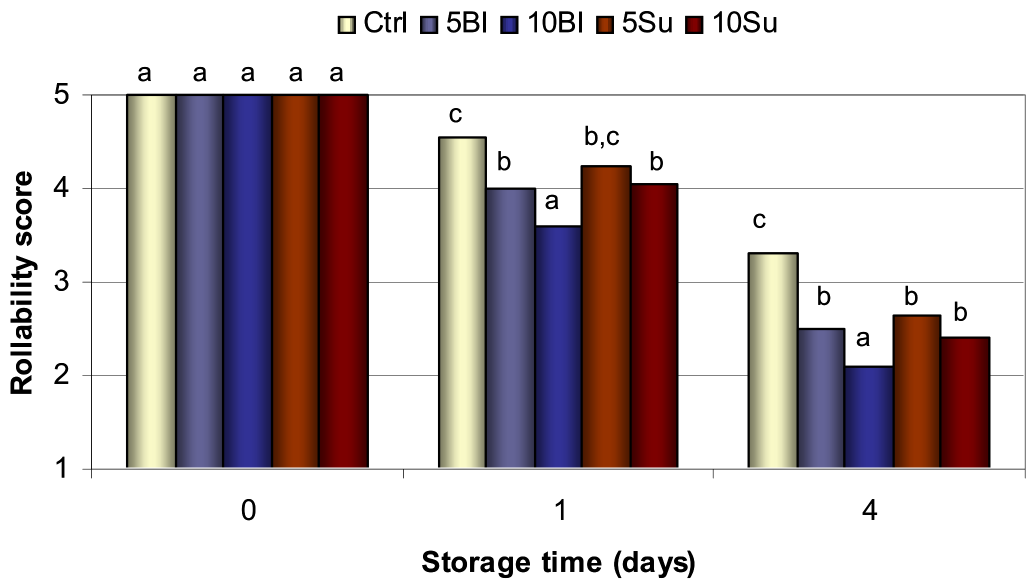

Figure 7. Rollability score of corn tortillas containing sorghum bran stored at 4ºC for up to four days. Values are means of 2 replicates, 5 observations each. Columns with the same letter are not significantly different (α= 0.05). 1= Unrollable, 5= Rolls without cracking or braking. For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, and Su= Sumac bran.

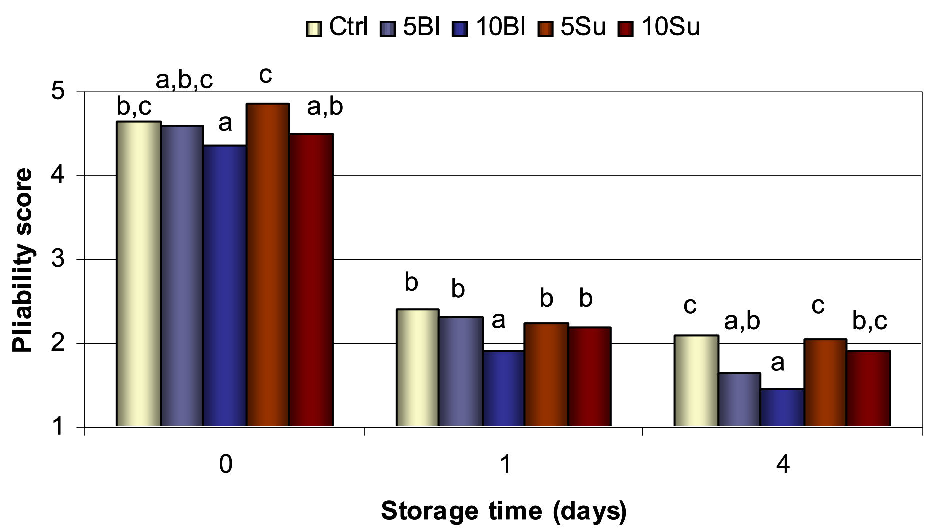

Figure 8. Pliability score of corn tortillas containing sorghum bran stored at 4ºC for up to four days. Values are means of 2 replicates, 5 observations each. Columns with the same letter are not significantly different (α= 0.05). 1= Complete crumbling, 5= Completely pliable. For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, and Su= Sumac bran

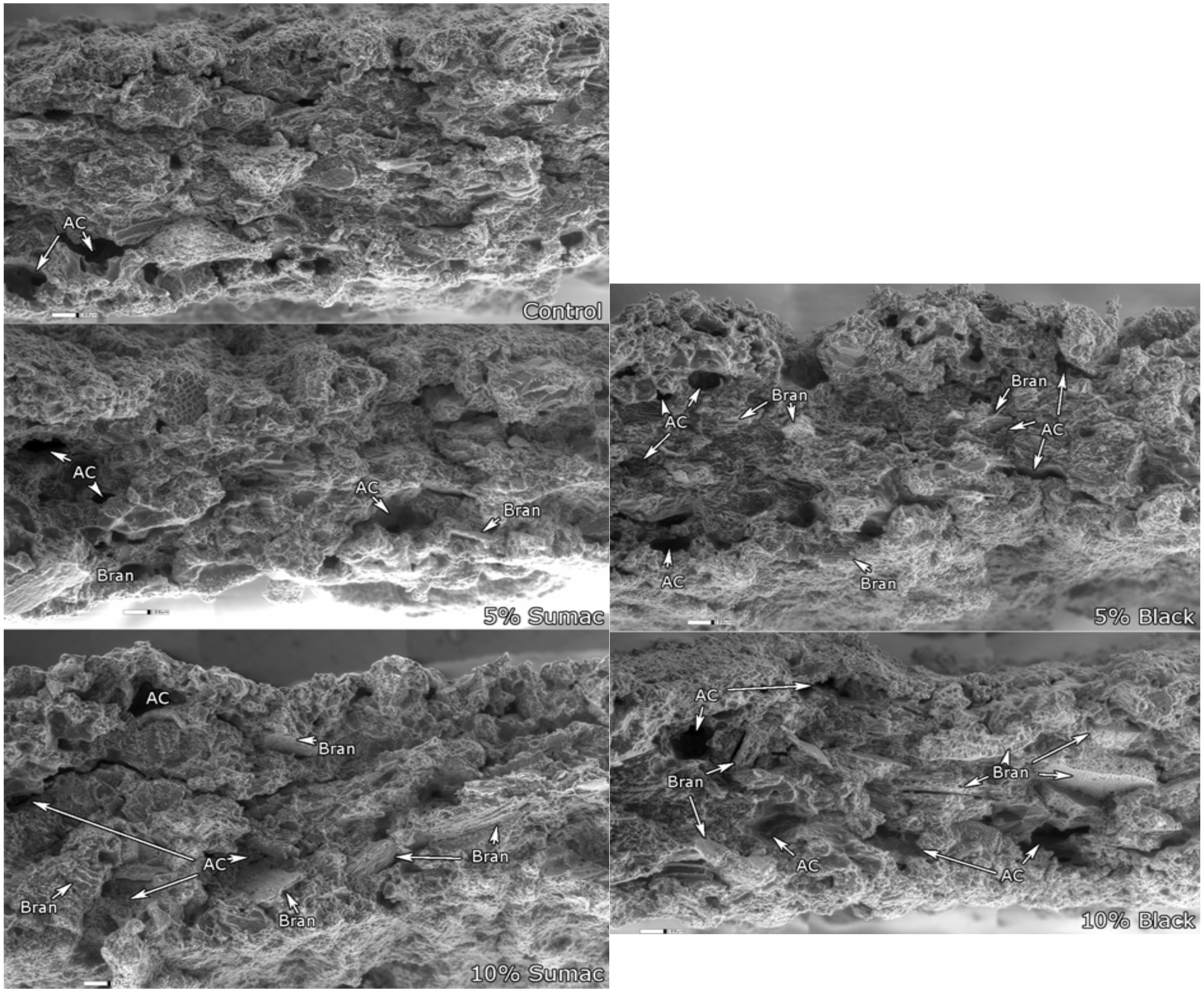

Figure 9. Structure of tortillas with and without sorghum bran.

Phenol levels and ABTS antioxidant activity

Tortillas containing sorghum bran had higher amounts of phenols and antioxidant activity than the control, which indicates that some of the bran antioxidant properties were retained throughout processing. Phenol levels and antioxidant activity increased as the level of bran increased (Figures 10 and 11, Appendix A). For the same level of bran, higher antioxidant activities and higher amounts of phenols were observed for tortillas containing Sumac bran. This was expected since Sumac bran had higher concentration of phenols and higher antioxidant capacity than Black sorghum bran (Table VII). Sumac bran contains tannins, which are 15-30 times more effective at quenching peroxyl radicals than simple phenolics or Trolox (Hagerman et al. 1998).

Tortilla antioxidant activity can be increased up to four times by adding Sumac bran. Assuming that the ORAC value of sorghum products is 3-4 times higher than the ABTS value (Awika et al. 2003), one serving (55 g) of tortilla containing 5% Sumac bran would have an antioxidant activity equivalent to that of 60 g of blueberries (62.2 μmol TE/g fresh weight, Wu et al. 2004). Sorghum bran from specialty sorghums could be used to formulate cereal-based products with antioxidant levels comparable to that of blueberries, a fruit that is widely recognized for its high antioxidant value.

Assayable phenols and antioxidant activity were highly correlated (Fig. 12). About 93% of the variation in antioxidant activity could be explained by the amount of phenols. Hence, the phenol content of tortillas containing sorghum bran is a good predictor of in vitro antioxidant activity. Previous studies have shown that sorghum phenol content correlates strongly with antioxidant activity measured by various methods, indicating that these compounds are largely responsible for the activity (Awika 2003). Moreover, several authors have reported similar correlations between phenols and antioxidant activity of various products determined by different methods (Awika 2000, 2003, Adom and Liu 2002, Proteggente et al. 2002).

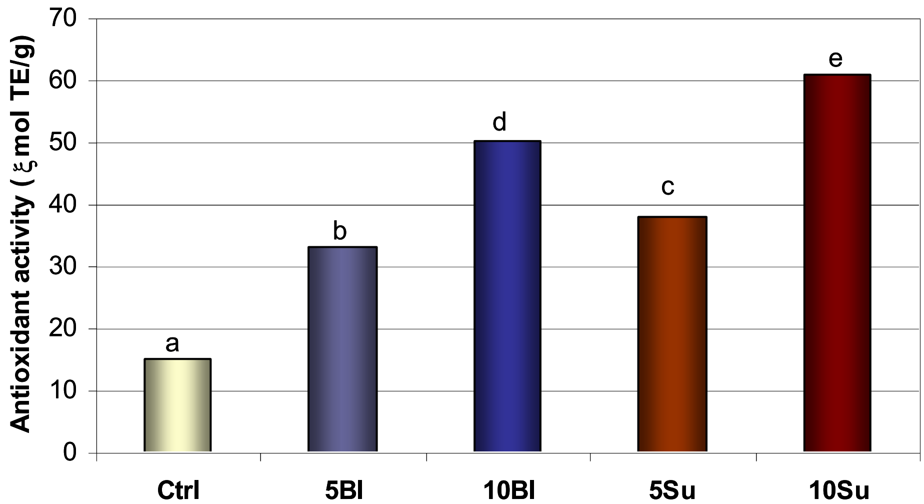

Figure 10. ABTS antioxidant activity (μmol TE/g) of corn tortillas containing sorghum bran. Values are means of 2 replicates, 3 observations each. Columns with the same letter are not significantly different (α= 0.05). TE= Trolox equivalents. For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, and Su= Sumac bran.

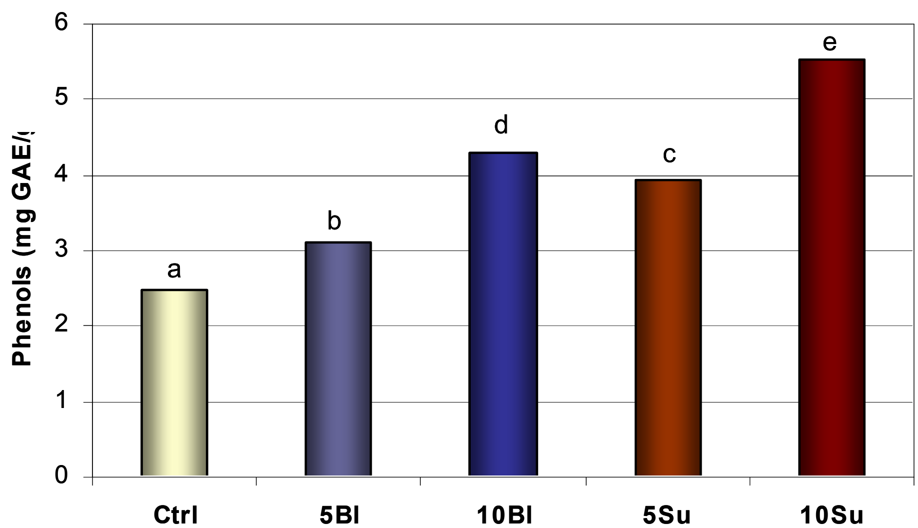

Figure 11. Phenol levels (mg GAE/g) of corn tortillas containing sorghum bran. Values are means of 2 replicates, 3 observations each. Columns with the same letter are not significantly different (α= 0.05). GAE= Gallic acid equivalents. For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, and Su= Sumac bran.

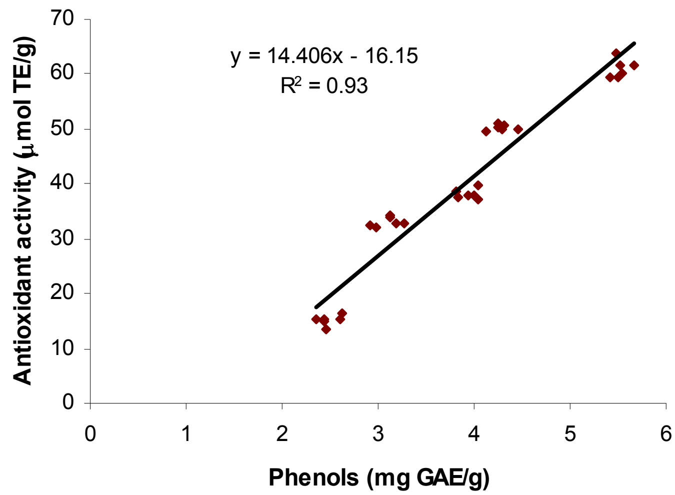

Figure 12. Correlation between ABTS antioxidant activity and level of phenols in tortillas containing sorghum bran.

Phenols and ABTS antioxidant activity of the raw materials

Phenols and antioxidant potential of dry ingredients (nixtamalized corn flour (NCF), sorghum bran, and preservatives) and masa samples were determined to assess the effect of processing on those parameters. Three forms of masa were evaluated: fresh, dried at 60°C for 12 h, and freeze-dried.

Phenol content of NCF plus preservatives (3.44 GAE/g db) was slightly higher than phenol levels reported for white corn (3.00 GAE/g db) (Xu, 2004). In regards to antioxidant potential, white corn was reported as 11.96 µmol TE/g (Xu 2004) whereas measured NCF antioxidant activity was 11.37 µmol TE/g. Although it is not a fair comparison since the corn analyzed was not the same utilized for NCF production, it can be hypothesized that an increase in phenol extractability occurred due to processing of corn into NCF. Alkaline cooking may release bound phenolic acids from the breakdown of cellular constituents. Dewanto et al. (2002) showed that thermal processing of sweet corn (115 °C, 25 min) significantly elevated the total antioxidant activity by 44% and phenolics by 54%.

Regardless of preparation steps, all sets of samples showed the same trend. The control had the lowest amount of phenols and the lowest antioxidant potential, whereas the highest values corresponded to the treatment containing 10% Sumac bran (Figs. 13, 14, Appendix A). Although the trend was similar, actual values were different. Hydration and mixing steps involved in masa preparation caused a reduction in extracted phenols. Sumac bran treatments had more of a reduction than their counterpart containing Black sorghum bran. The reduction in the amount of phenols was consistent with a decreased antioxidant activity only for treatments containing Sumac bran. Sumac bran has tannins, which are known to bind food macromolecules forming insoluble complexes (Hagerman and Butler 1981, Haslam 1974, Naczk and Shaidi 1997). Such complexes are hard to extract for analysis, and this may partly account for the reduced antioxidant potential.

Drying (60˚C, 12 h) caused a further reduction in both antioxidant activity and assayable phenols. Heat could have accelerated binding of NCF constituents with phenols. Again a stronger reduction was observed in samples containing Sumac bran. Dried samples had the lowest antioxidant activity, but not the lowest amount of phenols

(Figs. 12, 13, Appendix A), which was unexpected since phenols are considered largely responsible for the antioxidant activity of sorghums (Awika et al. 2003).

Unlike solutions utilized for antioxidant activity, samples used for phenol determination exhibited cloudiness. Turbidity may have interfered with spectrophotometer readings compromising the results. When observed under the microscope, particulates such as reminats of starch, endosperm pieces, and cell wall fragments were identified. Since most of the material exhibited birefringence when observed under polarized light, it is likely that the spectrophotometer readings were erroneous.

Methanol extracts were filtered through a glass microfiber filter using vacuum in order to prevent turbidity, but when water was added, the solution still turned cloudy. It is likely that the change in pH caused by water addition yielded precipitation, agglomeration, or brought out of solution some NCF constituents. Filtering the diluted extract (0.1 mL methanol extract plus 1.1 mL distilled water) yielded a clear solution; but when the analyses were completed, samples had even lower amounts of phenols than their processed counterparts. Although filters were chemically inert and binder free, some of the liquid containing phenol compounds could have been absorbed by the membrane, which could have produced lower values.

Since dry ingredients and masa analyses gave misleading results, the amount of phenols and the antioxidant activity were calculated by adding the contribution of the fraction of nixtamalized corn flour (NCF) and sorghum bran present in each treatment (Tables X and XI). Estimated amounts of phenols and antioxidant activity were larger than the measured values. Interaction of sorghum bran and NCF compounds may occur during the steps involved in masa preparation, thus it is likely that the calculated values are overestimating the amount of phenols and antioxidant potential of the samples.

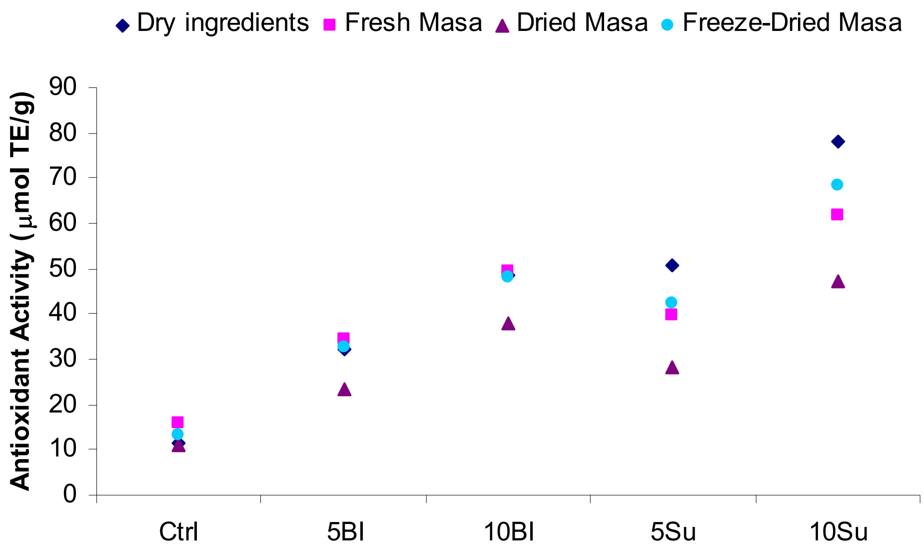

Figure 13. ABTS antioxidant activity (μmol TE/g) before processing. Values are means of 2 replicates, 2 observations each. TE= Trolox equivalents. For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, and Su= Sumac bran.

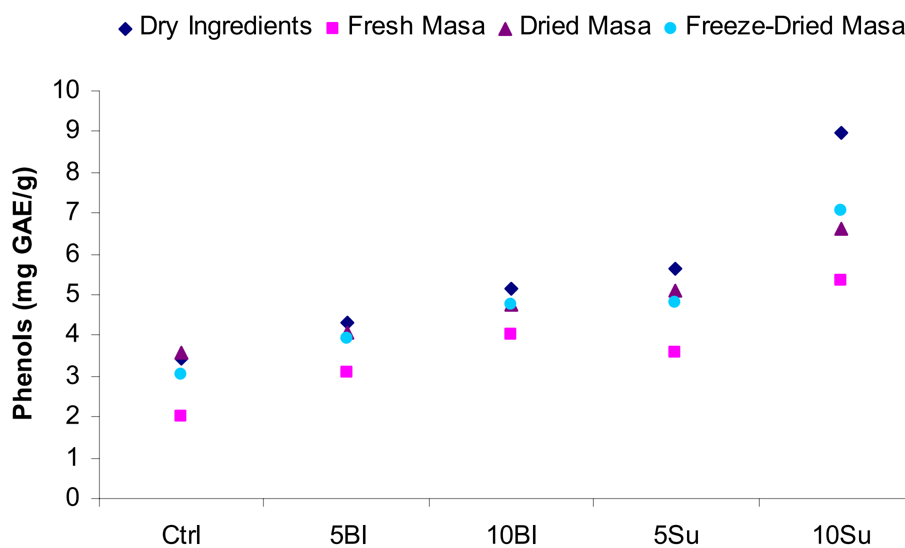

Figure 14. Levels of phenols (mg GAE/g) before processing. Values are means of 2 replicates, 2 observations each. GAE= Gallic acid equivalents. For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, and Su= Sumac bran.

Table X. Calculated amount of phenols (mg GAE/g) contributed by each fraction of ingredient. For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, and Su= Sumac bran.

Treatment	NCF	Sorghum bran		Total
		Black	Sumac	
Ctrl	3.4	-	-	3.4
5Bl	3.3	1.7	-	5.0
10Bl	3.1	3.3	-	6.4
5Su	3.3	-	4.2	7.5
10 Su	3.1	-	8.0	11.1

Table XI. Calculated ABTS antioxidant activity (µmol TE/g) contributed by each fraction of ingredient. For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, and Su= Sumac bran.

Treatment	NCF	Sorghum bran		Total
		Black	Sumac	
Ctrl	11.4	-	-	11.4
5Bl	10.9	23.3	-	34.2
10Bl	10.4	44.5	-	54.9
5Su	10.9	-	54.9	65.8
10 Su	10.4	-	104.9	115.3

Retention of phenols and ABTS antioxidant activity after processing

To evaluate the effects of processing on phenol levels and antioxidant properties of sorghum bran, the calculated values corresponding to unprocessed bran and nixtamalized corn flour (NCF) were compared with the values obtained from tortilla analyses. Values are shown in tables XII and XIII.

Tortillas without sorghum bran (Ctrl) retained more assayable phenols (72%) than tortillas with added sorghum bran (50-67%). The lower amount of extractable phenols in NCF was not accompanied by a reduction in antioxidant properties; on the contrary, an increase in the original antioxidant potential was observed. Tortilla processing elevated NCF original antioxidant activity by 33%. Formation of compounds with novel or improved antioxidant properties, such as Maillard reaction products, could have occurred (Nicoli et al. 1999).

Retention of phenols after processing was 50-53% for tortillas containing Sumac bran, and 62-67% for Black bran tortillas. Low phenol retention of Sumac bran products has been previously reported (Xu, 2004). The reduced amount of phenols in Sumac bran processed products was consistent with a reduction in the retention of antioxidant potential.

Black sorghum bran tortillas retained more antioxidant activity (92-97%) than their counterpart containing Sumac bran (53-58%). It is likely that anthocyanins, which are the major contributor to Black sorghums bran antioxidant activity (Awika et al. 2004), are more stable during tortilla processing than Sumac Bran antioxidants. Nevertheless differences could be due to extractability. Condensed tannins are known to bind to food components forming insoluble complexes, which could have decreased extractability

Although extractability of phenols decreased due to processing, it does not mean that they do not function as antioxidants in vivo. Tannins may remain active as antioxidants in the digestive tract even when they are complexed with food molecules (Hagerman et al. 1998, Marshall and Roberts 1990). The colon microflora can break those complexes down into phenolic acids, which are absorbed through the large intestine and provide antioxidant properties (Pietta et al. 1997, Deprez et al. 2000, Pietta 2000, Tapiero et al. 2002).

The measured antioxidant potential of tortillas containing sorghum bran could underestimate the biological potential of these products, since only the activity of the extractable compounds was measured. According to Adom and Liu (2002) the major portion of phenolics in grains existed in the bound form (85% in corn, 75% in oats and wheat, and 62% in rice), and bound phytochemicals were the major contributors to the total antioxidant activity of uncooked whole grains.

Dietary fiber

Tortilla dietary fiber was calculated using the dietary fiber values correspondent to the fractions of nixtamalized corn flour (NCF) and sorghum bran present in each treatment. A dietary fiber content of 10% was assumed for NCF, 38% for Sumac and 52% for Black bran. One serving (55 g) of tortillas containing sorghum bran at either level qualifies as a "good source of fiber" (Table XIV). Sorghum bran addition increased tortilla fiber content by 15 to 38%.The fiber content is likely underestimated since resistant starch is formed during tortilla processing and during storage (Rendon-Villalobos et al 2002).

Tortillas with sorghum bran and the antistaling formula

Two controls were utilized: Ctrl, which includes only nixtamalized corn flour (NCF) and preservatives, and Ctrl+A, the control with the antistaling formula (0.57% guar gum, 0.43% carboxymethylcellulose and 60 mg/kg maltogenic α-amylase). Interaction of the antistaling formula with sorghum bran was evaluated at two levels of Sumac and Black bran. The amounts of raw materials included in each formula are listed in Table XV.

Table XII. Retention of phenols (mg GAE/g) in table tortillas after processing. GAE= Gallic acid equivalents. For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, and Su= Sumac bran.

Treatment	Before[1]	After[2]	Retention (%)
Ctrl	3.4	2.5	72.1
5Bl	5.0	3.1	62.0
10Bl	6.4	4.3	66.6
5Su	7.5	3.9	52.7
10 Su	11.1	5.5	49.6

[1] Calculated values corresponding to unprocessed bran and nixtamalized corn flour.

[2] Measured values of tortilla samples.

Table XIII. Retention of ABTS antioxidant activity (µmol TE/g) in table tortillas after processing. TE= Trolox equivalents. For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, and Su= Sumac bran.

Treatment	Before[1]	After[2]	Retention (%)
Ctrl	11.4	15.2	133.3
5Bl	34.1	33.1	97.0
10Bl	54.9	50.2	91.6
5Su	65.7	38.2	58.1
10 Su	115.3	61.0	52.9

[1] Calculated values corresponding to unprocessed bran and nixtamalized corn flour.

[2] Measured values of tortilla samples.

Table XIV. Dietary fiber content (g/serving) of tortillas containing sorghum bran estimated by adding the contributions of NCF and sorghum bran fractions. For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, and Su= Sumac bran.

Treatment	NCF	Sorghum bran		Total
		Black	Sumac	
Control	2.6	-	-	2.6
5Bl	2.5	0.7	-	3.2
10Bl	2.4	1.2	-	3.6
5Su	2.5	-	0.5	3.0
10 Su	2.4	-	0.9	3.3

Physical properties

In terms of moisture content, no significant differences were found among masas (Appendix B), aside from the treatment containing 10% Sumac, which had slightly lower moisture content. The additional water incorporated was enough to hydrate the NCF and the bran yielding masas with moisture content similar to the control. Tortilla moisture was between 47% and 48%. No statistical differences were found (Table XVI). Tortillas containing sorghum bran had greater pH than both controls (Table XVI). Fumaric acid, which acidulates the system, was added at 0.4 baking percentage. An adjustment may be necessary to account for the increase in dry matter when sorghum bran is included in the formula.

The appearance of tortillas containing sorghum bran and the antistaling formula is shown in Figure 15. Tortillas containing the antistaling formula were fluffier and had more brown spots than the control. The control with the antistaling formula (Ctrl+A) was different from the control without additives (Ctrl). Although brown spots were observed, objective measurements indicated that Ctrl+A was lighter and less yellow than Ctrl (Figure 16, Appendix B). As mentioned above, tortillas prepared with the antistaling formula, were fluffier, and differences in product structure could affect the way in which light is reflected, transmitted, absorbed or refracted, which in turn translates into a different color perception. Tortillas containing sorghum bran had significantly different color than both controls (Appendix B). As the level of sorghum bran increased, tortilla darkness increased, Black bran had a stronger effect. Sorghum bran addition caused a reduction in the yellow hue and an increase in the red hue.

Table XV. Treatments codes and formulation (g). For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, Su= Sumac bran and A= Additives.

Treatment	DMF	Water	Sorghum bran		Potassium Sorbate	Fumaric Acid	Guar	CMC	alpha-amylase
			Black	Sumac					
Ctrl	1000	1200	-	-	5	4	-	-	-
5Bl+A	1000	1250	50	-	5	4	5.3	4.7	0.06
10Bl+A	1000	1300	100	-	5	4	5.3	4.7	0.06
5Su+A	1000	1250	-	50	5	4	5.3	4.7	0.06
10Su+A	1000	1300	-	100	5	4	5.3	4.7	0.06
Ctrl+A	1000	1200	-	-	5	4	5.3	4.7	0.06

Table XVI. Moisture content (%) and pH of tortillas containing sorghum bran and the antistaling formula. Values are means of 2 replicates, 3 observations each. Means in the same column followed by the same letter are not significantly different (α= 0.05). For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, Su= Sumac bran, and A= Additives.

Treatment	Moisture (%)	pH
Ctrl	47.4 [a]	5.2 [a]
5Bl+A	47.7 [a]	5.2 [a]
10Bl+A	47.8 [a]	5.3 [b]
5Su+A	47.5 [a]	5.3 [b]
10Su+A	46.7 [a]	5.3 [c]
Ctrl+A	48.1 [a]	5.2 [a]

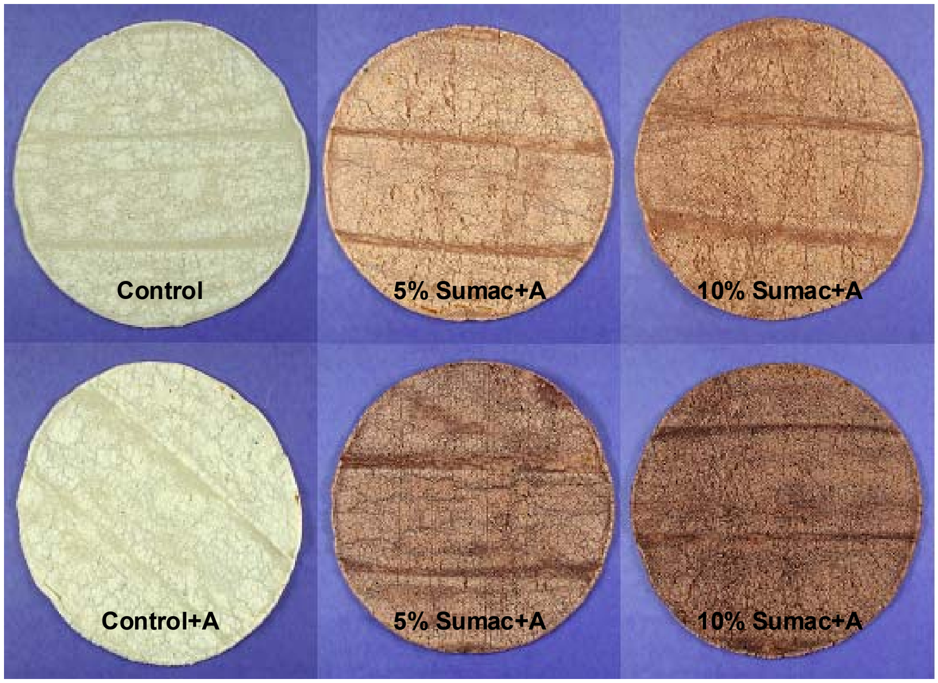

Figure 15. Appearance of tortillas containing sorghum bran and the antistaling formula. A= Additives.

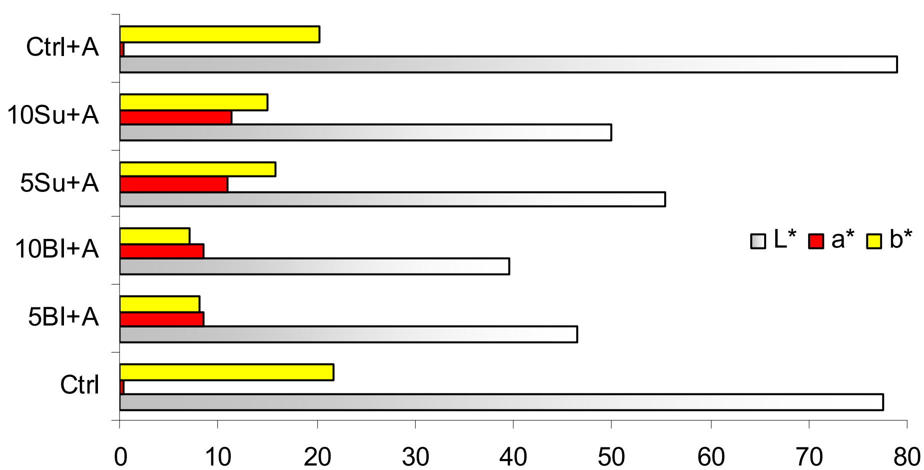

Figure 16. Color of corn tortillas containing sorghum bran and the antistaling formula, where L* indicates lightness, a* indicates hue on a green (-) to red (+) axis, and b* indicates hue on a blue (-) to yellow (+) axis. Values are means of 2 replicates, 3 observations each. For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, Su= Sumac bran, and A= Additives.

Texture

Results from the 1-D extensibility evaluation are shown in Figures 17, 18 and appendix B. Lower rupture force and modulus of deformation, as well as higher rollability and pliability scores were observed for the control containing the antistaling formula (Ctrl+A) (Figs. 17-20). Ctrl+A tortillas were softer and remained more flexible for a longer period of time. At four days of cold storage tortillas still had acceptable rollability and pliability scores. Maltogenic α-amylase, carboxymethylcellulose (CMC) and guar gum delayed tortilla staling, as previously reported by Gutierrez De Velasco (2004). The mechanism of action remains unknown, but it is has been hypothesized that maltogenic α-amylase weakens the tortilla structure by trimming the starch polymers, while guar interferes with amylopectin recrystallization, and CMC maintains the disrupted tortilla structure by creating a flexible matrix (Bueso et al. 2004, Gutierrez De Velasco 2004).

The interaction of sorghum bran with the antistaling formula caused further reduction in both, rupture force and modulus of deformation (Figs. 17, 18). This could be associated with softer tortillas, nevertheless for an improvement in texture to occur, the reduction in force and modulus of deformation should occur along with good subjective texture. In this case, only tortillas containing Sumac bran had acceptable rollability and pliability scores (Figs.19, 20, Appendix B). Even though their scores were not as good as the ones reached by Ctrl+A, tortillas containing Sumac bran had improved texture. No significant differences were found between tortillas containing Sumac bran and the control, even with up to 10% Sumac bran addition. On the other hand, treatments with Black bran had lower scores than the control. It is likely that the structure lost caused by the large bran pieces present in Black bran and by the maltogenic α-amylase, was not overcome by CMC and guar gum. The concentration of those additives could be optimized as an attempt to strengthen the continuous matrix that holds tortillas together.

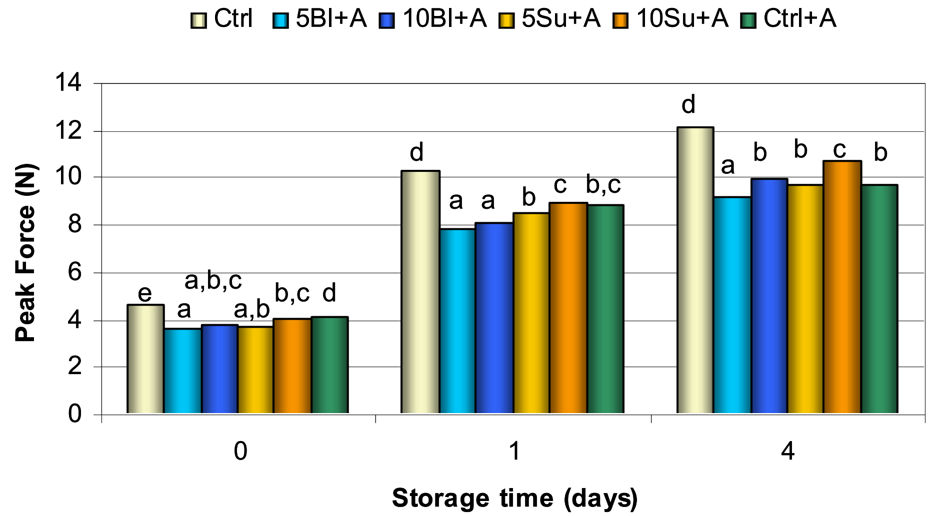

Figure 17. Rupture force (N) of corn tortillas containing sorghum bran and the antistaling formula, stored at 4ºC for up to four days. Values are means of 2 replicates, 10 observations each. Columns with the same letter are not significantly different (α= 0.05). For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, Su= Sumac bran, and A= Additives.

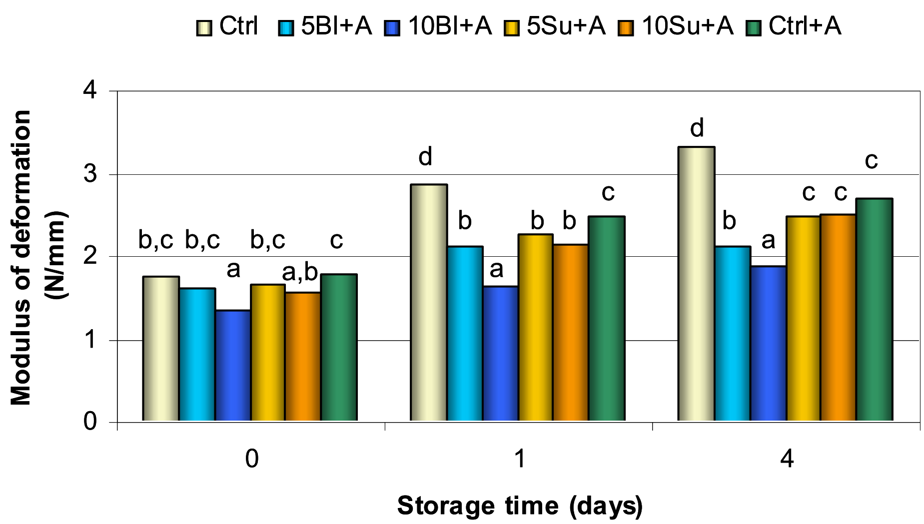

Figure 18. Modulus of deformation (N/mm) of corn tortillas containing sorghum bran and the antistaling formula stored at 4ºC for up to four days. Values are means of 2 replicates, 10 observations each. Columns with the same letter are not significantly different (α= 0.05). For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, Su= Sumac bran and A= Additives.

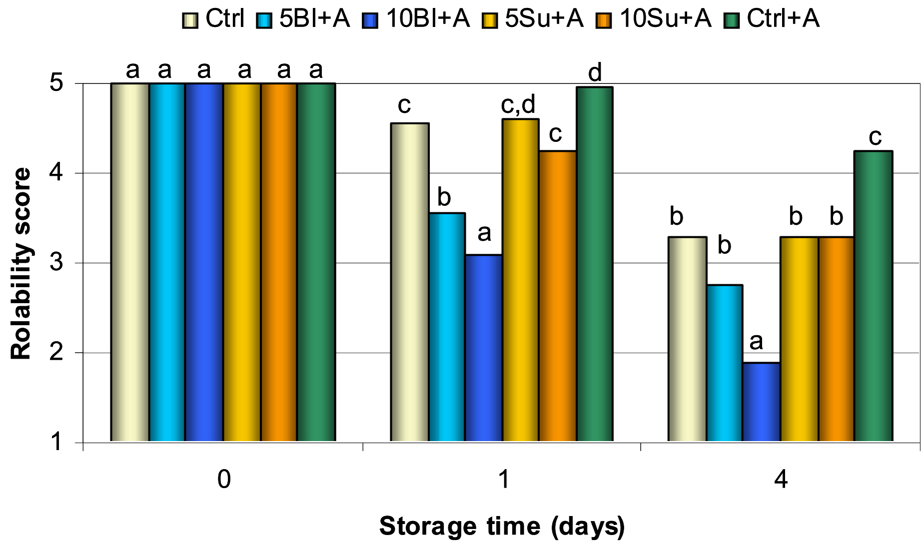

Figure 19. Rollability score of corn tortillas containing sorghum bran and the antistaling formula, stored at 4ºC for up to four days. Values are means of 2 replicates, 5 observations each. Columns with the same letter are not significantly different (α= 0.05). 1= Unrollable, 5= Rolls without cracking or braking. For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, Su= Sumac bran and A= Additives.

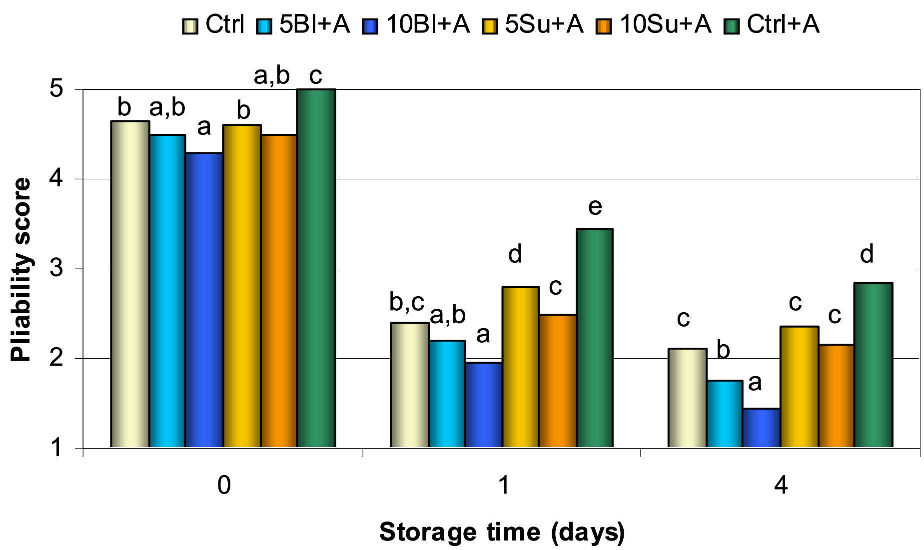

Figure 20. Pliability score of corn tortillas containing sorghum bran and the antistaling formula stored at 4ºC for up to four days. Values are means of 2 replicates, 5 observations each. Columns with the same letter are not significantly different (α= 0.05). 1= Complete crumbling, 5= Completely pliable. For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, Su= Sumac bran, and A= Additives.

Phenol levels and ABTS antioxidant activity

There were significant differences in the phenol levels and antioxidant activities of tortillas containing sorghum bran. As the level of bran addition increased, antioxidant capacity and phenols increased (Figs. 21, 22 and Appendix B). As in tortillas without additives, for the same level of bran addition tortillas containing Sumac bran had the highest amounts of phenols and antioxidant potential. This could be attributed to the high antioxidant capacity of Sumac bran tannins.

A high correlation between assayable phenols and antioxidant activity was found (R^2 = 0.93) (Fig. 23). This corroborates that the phenol content of tortillas could be a good predictor of antioxidant activity.

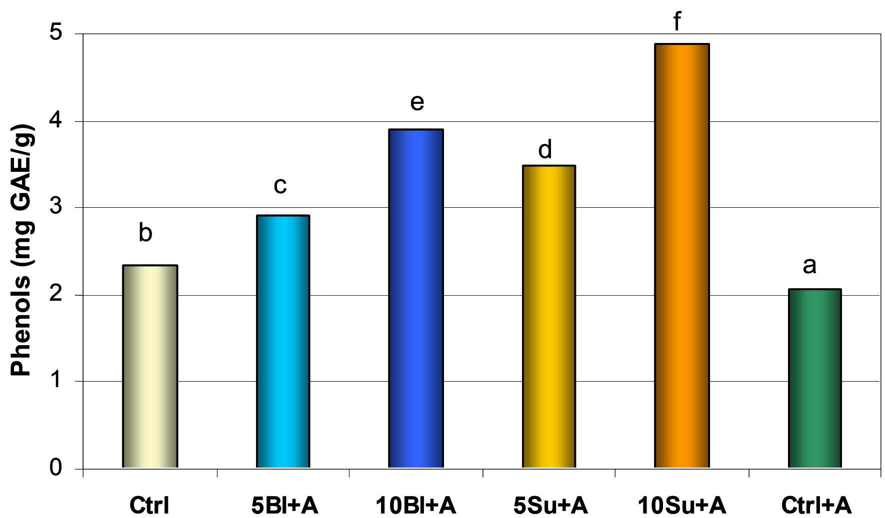

Figure 21. Phenol levels (mg GAE/g) of corn tortillas containing sorghum bran and the antistaling formula. Values are means of 2 replicates, 3 observations each. Columns with the same letter are not significantly different (α= 0.05). GAE= Gallic acid equivalents. For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, Su= Sumac bran, and A= Additives.

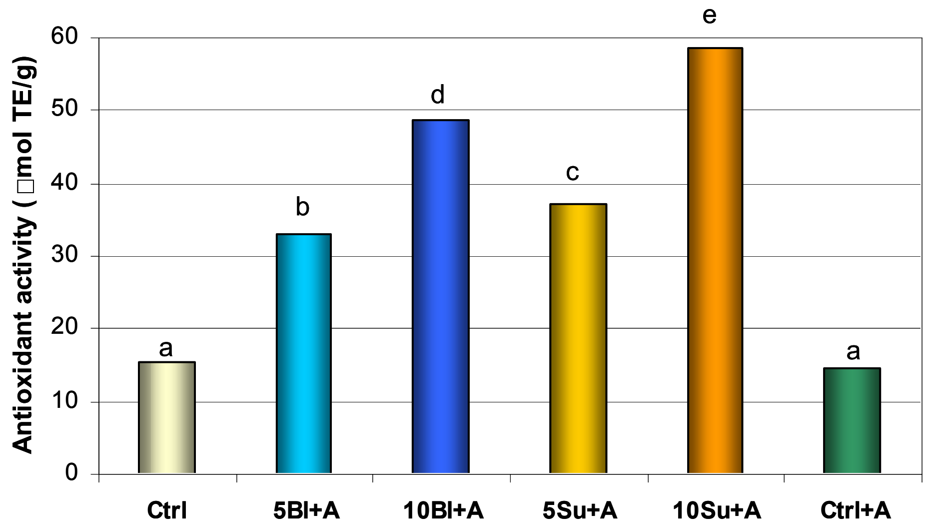

Figure 22. ABTS antioxidant activity (μmol TE/g) of corn tortillas containing sorghum bran and the antistaling formula. Values are means of 2 replicates, 3 observations each. Columns with the same letter are not significantly different (α= 0.05). TE= Trolox Equivalents. For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, Su= Sumac bran and A= Additives.

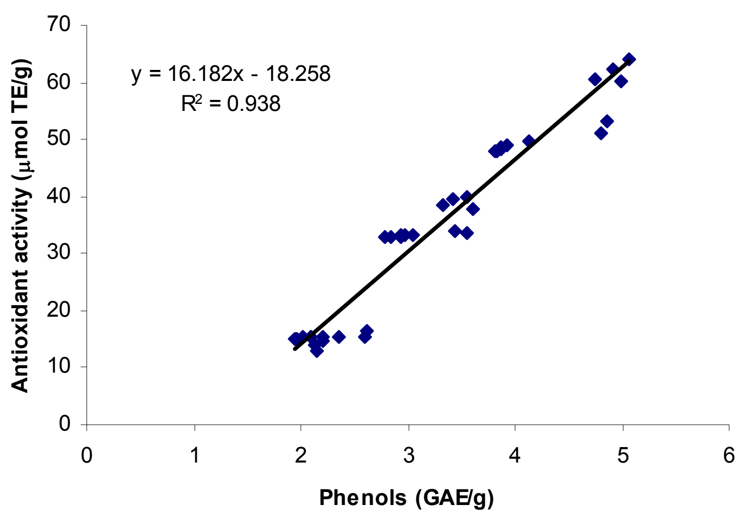

Figure 23. Correlation between ABTS antioxidant activity and level of phenols in tortillas containing sorghum bran and the antistaling formula.

Retention of phenols and ABTS antioxidant activity after processing

Estimated phenol levels and antioxidant values of the raw materials, and measured values of tortilla samples were utilized to determine the effect of processing on phenols and antioxidant potential. The retention of phenols was higher for both controls than for tortillas containing sorghum bran (Table XVII). Tortillas without sorghum bran showed a reduction in phenolics of about 40%, whereas products containing sorghum bran had a reduction as pronounced as 56%. Phenols naturally occurring in corn could be more stable than the ones present in sorghum bran.

The antistaling formula caused a further reduction in phenol retention rates. Ctrl+A extractable phenols were reduced by 38.9% whereas Ctrl phenols decreased only by 32.3%. The reduction in phenolics was not accompanied by a reduction in antioxidant properties (Table XVIII). To the contrary, tortilla processing elevated the original antioxidant activity by 28 to 37%. Formation of compounds with novel or improved antioxidant properties (i.e. Maillard reaction products) could have occurred (Nicoli et al. 1999).

Sumac bran products had lower phenol retention rates (44-47%) than Black bran tortillas (58-61%). The reduction in phenols was consistent with a decreased antioxidant potential (XVIII). As previously mentioned, this could be attributed to formation of complexes between tannins and nixtamalized corn flour compounds. Unlike Sumac bran added tortillas, Black bran tortillas had reduced phenol levels but did not have reduced antioxidant activity. Retention of antioxidant activity was between 89 and 97%. An Improvement of the antioxidant properties of the remaining polyphenols could have taken place. Increased antioxidant properties of certain polyphenols may occur as a consequence of a change of their oxidation state. Poplyphenols with an intermediate oxidation state can exhibit higher radical scavenging efficiency than the non-oxidized ones (Nicoli et al. 1999).

Table XVII. Retention of phenols (mg GAE/g) in table tortillas with additives after processing. GAE = Gallic acid equivalents. For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, Su= Sumac bran and A= Additives.

Treatment	Before[1]	After[2]	Retention (%)
Ctrl	3.4	2.3	67.7
5Bl+A	5.0	2.9	58.4
10Bl+A	6.4	3.9	60.8
5Su+A	7.5	3.5	46.6
10 Su+A	11.1	4.9	44.0
Ctrl+A	3.4	2.1	60.2

[1] Calculated values corresponding to unprocessed bran and nixtamalized corn flour.

[2] Measured values of tortilla samples.

Table XVIII. Retention of ABTS antioxidant activity (μmol TE) in table tortillas with additives after processing. TE= Trolox equivalents. For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, Su= Sumac bran, and A= Additives.

Treatment	Before[1]	After[2]	Retention (%)
Control	11.4	15.5	136.6
5Bl+A	34.1	33.2	97.2
10Bl+A	54.9	48.6	88.6
5Su+A	65.7	37.3	56.7
10 Su+A	115.3	58.5	50.8
Ctrl+A	11.4	14.5	127.9

[1] Calculated values corresponding to unprocessed bran and nixtamalized corn flour.

2 Measured values of tortilla samples.

Dietary fiber

Following the Prosky procedure the dietary fiber content of tortillas containing 10% Sumac bran plus additives was 10.2 w/w % (db). According to this result, the dietary fiber content of 10Su+A tortillas would be 3.0 g per serving, which makes them "a good source of fiber".

Sensory evaluation

To investigate eating qualities, 5% sorghum bran tortillas were evaluated for appearance, aroma, texture and flavor. The control containing additives (Ctrl+A) was used as control. Tortillas were evaluated by untrained panelists (n=30) using a 9 point hedonic scale, where 1 was defined as "dislike extremely" and 9 as "like extremely". Scores ranged from 5.4 to 7.2 (Table XIX), which indicated that tortillas were liked. Sorghum bran did not compromise tortilla acceptability.

Bran addition caused no significant differences in ratings for any of the attributes aside from appearance. Ctrl+A appearance was preferred over tortillas containing sorghum bran (Table XIX). Sorghum bran imparts a natural dark color that could appeal to health conscious consumers, who associate dark colors with healthy products, or perceived as negative by consumer who preferred tan products. The successful use of blue corn in the production of dark colored food suggests a potential use for pigmented sorghums in the production of dark tortillas.

The inability to detect significant differences from the control indicates that 5% sorghum bran could be used without causing major changes in tortilla sensory properties.

Table XIX. Sensory evaluation of tortillas. Means in the same column followed by the same letter are not significantly different (α= 0.05). For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, Su= Sumac bran, and A= Additives.

	Appearance	Aroma	Texture	Flavor
Ctrl+A	7.2 ± 1.4 ^{b}	7.1 ± 1.1 ^{a}	6.9 ± 1.4 ^{a}	6.9 ± 1.3 ^{a}
5Bl+A	5.4 ± 1.8 ^{a}	6.5 ± 1.4 ^{a}	6.5 ± 1.6 ^{a}	6.5 ± 1.4 ^{a}
5Su+A	6.1 ± 1.6 ^{a}	6.7 ± 1.1 ^{a}	6.5 ± 1.5 ^{a}	6.4 ± 1.4 ^{a}

Comparison of tortillas with and without additives

Appearance and color

Differences in appearance among tortillas with and without additives were observed (Figure 24). Tortillas with the antistaling formula were lighter than tortillas without it (Appendix C). The antistaling formula made fluffier tortillas (Table XX). Differences in product structure could affect the way in which light behaves and consequently color perception. Thus, the visually perceived changes could be due to structural rather than color changes.

Objective color measurements showed that tortillas with the antistaling formula had increased L* values over tortillas without additives (Figure 25, Appendix C), which corroborates that tortillas were lighter. The red and yellow hue of tortillas containing sorghum bran remained the same, whereas for the control, the antistaling formula caused a reduction in the yellow hue (Figure 25, Appendix C).

Although the antistaling formula produced brown spots on the tortilla surface, the objective color measurements did no show differences between tortillas with or without additives. This was probably because the browns spots were randomly distributed across the tortilla surface, and color measurements were taken only at the center of three tortillas. Measurement of color at three or more points of each tortilla could reflect the changes in color caused by the inclusion of additives. Brown spots were probably caused by the addition of the enzyme. The amount of reducing sugars available for maillard browning may have been increased by the action of maltogenic alpha-amylase.

Height

The additives yielded fluffier tortillas. Differences were not only visually perceived (Figure 26), they were also reflected by an increase in tortilla height (Table XX). The height of a10 tortilla stack was increased by up to 3 mm (12%) when additives were utilized (Table XX). Although the effect was stronger for the control, the antistaling formula was still effective in the presence of sorghum bran. Differences among treatments with and without the additives were significant for all cases (Table XX).

The advantage of having a fluffier product comes into play at the point of sale, where consumers touch the package of tortillas as means to evaluate tortilla softness. Texture along with appearance has an impact on the consumer's perception of a "good tortilla".

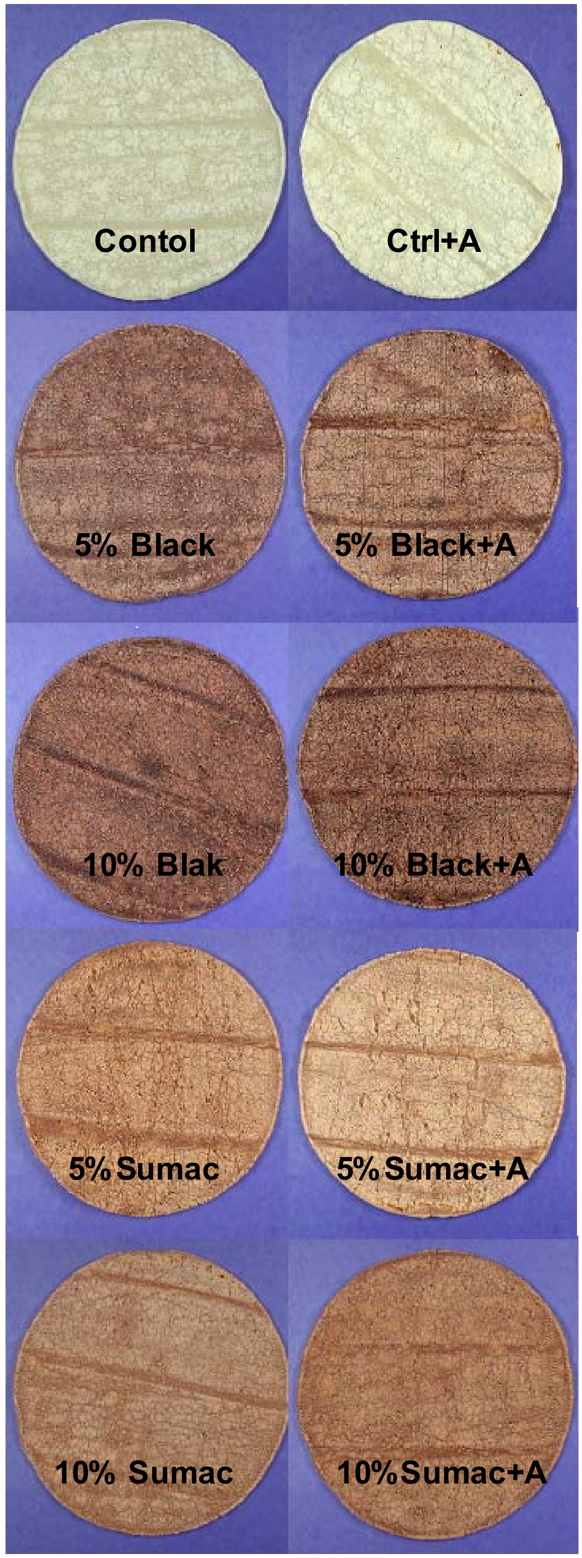

Figure 24. Appearance of tortillas with and without additives (right and left column, respectively).

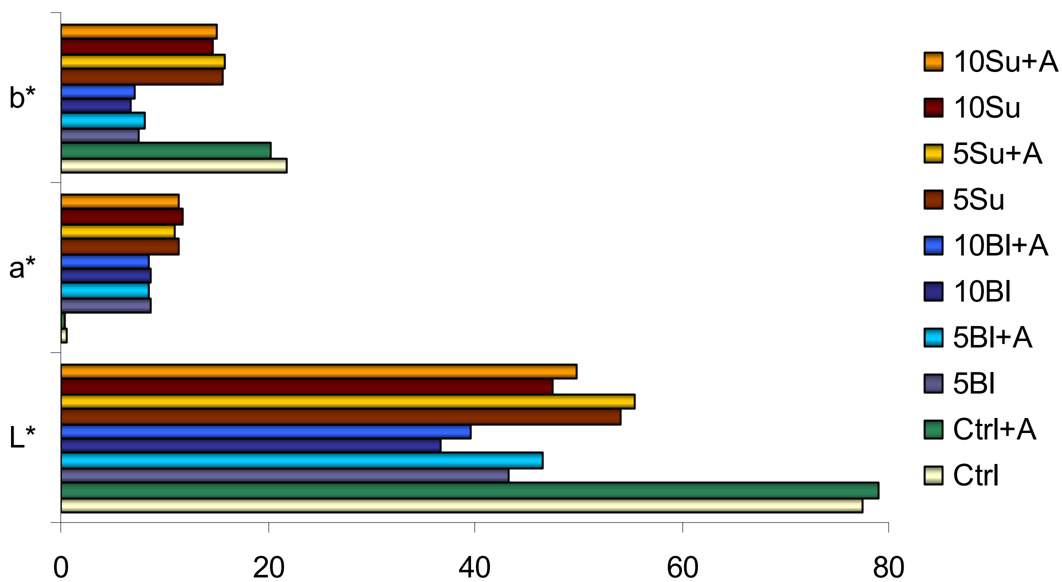

Figure 25. Color of corn tortillas containing sorghum bran with and without additives. L* indicates lightness, a* indicates hue on a green (-) to red (+) axis, and b* indicates hue on a blue (-) to yellow (+) axis. Values are means of 2 replicates, 3 observations each. For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, Su= Sumac bran, and A= Additives.

Table XX. Height of 10 tortillas (mm). Values are means of 4 observations. Means followed by the same letter are not significantly different (α= 0.05). For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, and Su= Sumac bran.

Treatment	Without additives	With additives	Increase (%)
Ctrl	24.0 ± 0.3 [a]	26.9 ± 0.2 [d]	12.0
5Bl	24.0 ± 0.1 [a]	25.2 ± 0.3 [c]	5.2
10Bl	24.1 ± 0.1 [a]	24.8 ± 0.1 [b]	2.9
5Su	24.0 ± 0.3 [a]	25.4 ± 0.1 [c]	6.2
10Su	24.1 ± 0.1 [a]	25.3 ± 0.2 [c]	4.9

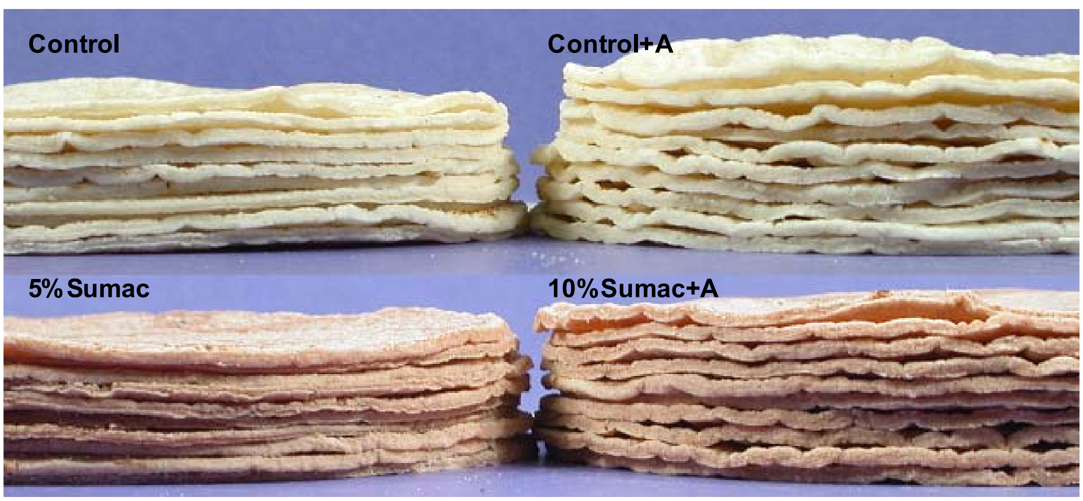

Figure 26. Stack of 10 tortillas. A) Ctrl, b) Ctrl+A, c) 5Su, d) 5Su+A. For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, Su= Sumac bran, and A= Additives.

Texture

Aside from tortillas containing 10% Black bran, no significant differences were found in terms of modulus of deformation among fresh tortillas with and without additives (Appendix C). Upon storage, tortillas containing the antistaling formula had significantly lower modulus of deformation than their counterparts without additives. Hugh-Iten et al. (2003) reported that bread baked with maltogenic alpha-amylase had a higher initial firmness and a lower firming rate than control bread, suggesting that the enzyme was most effective in preventing firming during aging. In the tortilla system, enzyme treated tortillas initially did not show an effect on the modulus of deformation, but the staling rate was delayed upon storage as indicated by lower modulus of deformation values.

After four days of cold storage tortillas containing additives and 10% black sorghum bran or 5% sumac bran (5SU+A and10Bl+A, respectively) had objective texture similar to the control containing additives (Ctrl+A) (Figs. 27, 28), which has been reported to have improved texture over the control (Ctrl) (Gutierrez de Velasco 2004). Low rupture force and modulus of deformation values suggest that tortillas containing the antistaling formula were soft (Appendix C). Nevertheless, as previously mentioned, for an improvement in texture to occur the reduction in objective texture values should occur along with an improvement in subjective texture.

In general, the control had the greatest improvement in subjective texture scores (Figs. 29, 30). Aside from the control, additives yielded an increase in rollability and pliability scores only for Sumac bran treatments (Appendix C). Thus, the antistaling formula produced tortillas with improved texture only when Sumac bran was utilized. The detrimental effect of Black bran addition was not overcome by the combination of additives tested. Different levels of the additives evaluated, or other additives may have to be included in the formula to prevent black sorghum bran tortillas from crumbling.

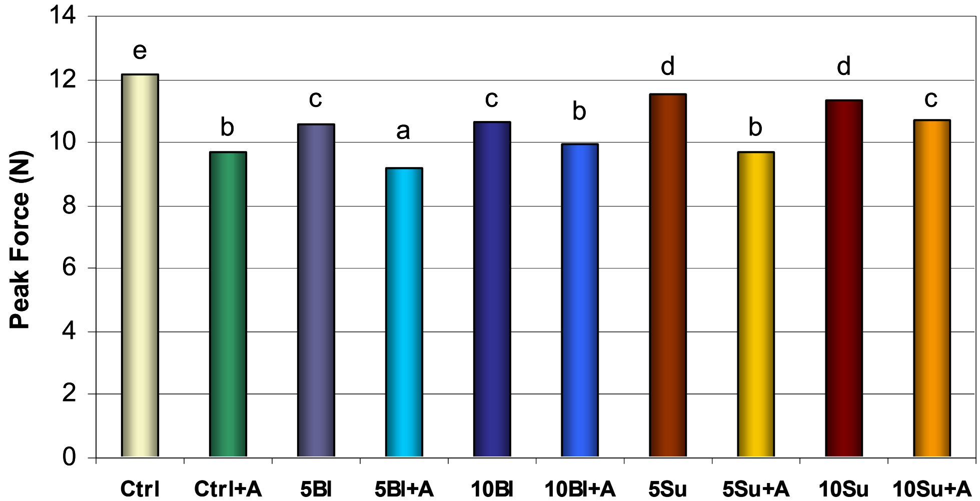

Figure 27. Rupture force (N) of corn tortillas containing sorghum bran, with and without additives, stored for 4 days at 4ºC. Values are means of 2 replicates, 10 observations each. Columns with the same letter are not significantly different (α= 0.05). For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, Su= Sumac bran, and A= Additives.

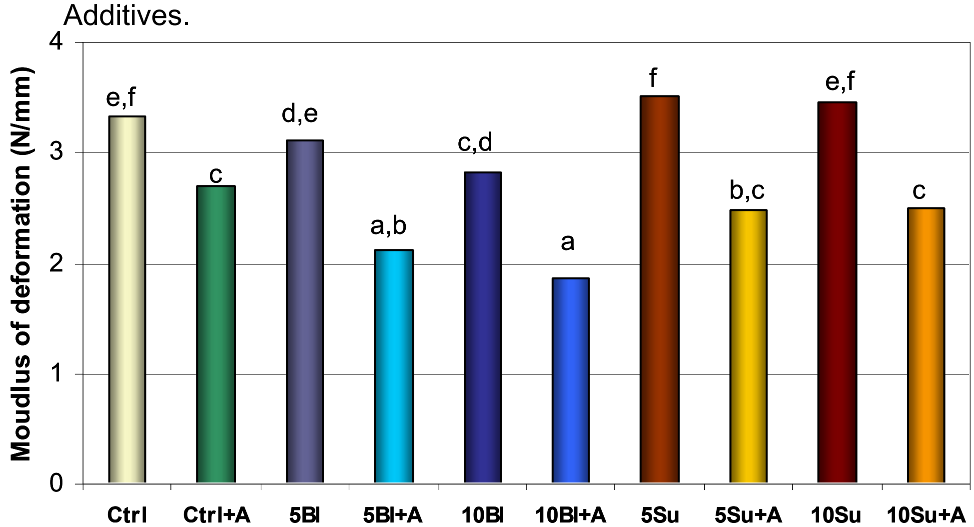

Figure 28. Modulus of deformation (N/mm) of corn tortillas containing sorghum bran, with and without additives, stored for 4 days at 4ºC. Values are means of 2 replicates, 10 observations each. Columns with the same letter are not significantly different (α= 0.05). For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, Su= Sumac bran, and A= Additives.

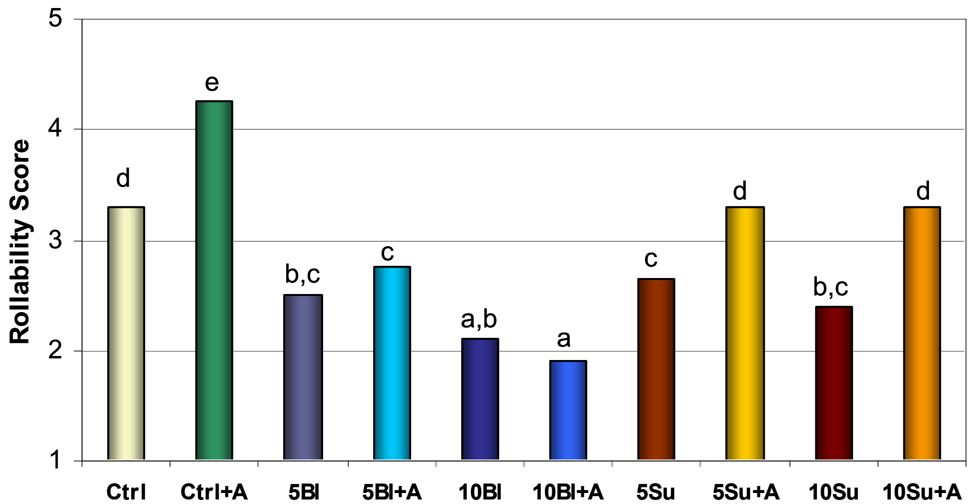

Figure 29. Rollability score of corn tortillas containing sorghum bran, with and without additives stored at 4ºC for up to four days. Values are means of 2 replicates, 5 observations each. Columns with the same letter are not significantly different (α= 0.05). 1= unrollable, 5= Rolls without cracking or braking. For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, Su= Sumac bran, and A= Additives.

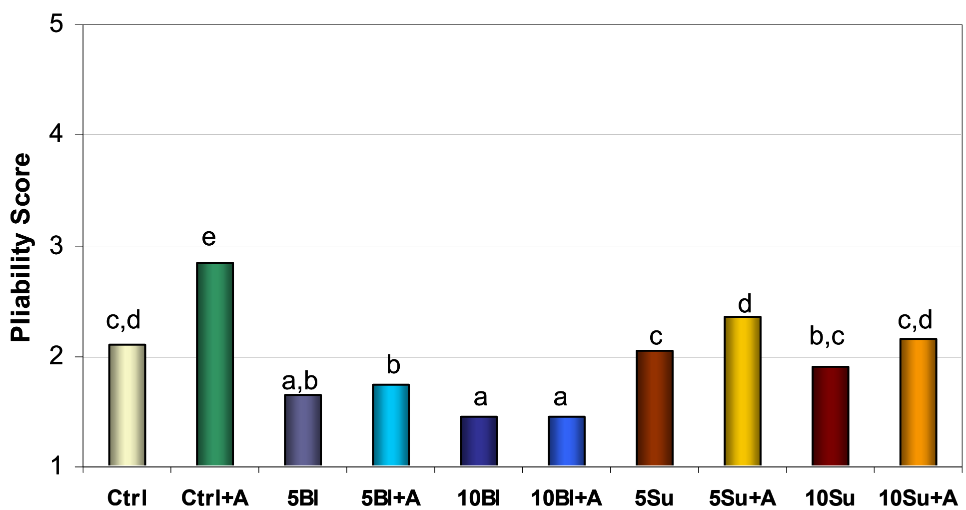

Figure 30. Pliability score of corn tortillas containing sorghum bran, with and without additives, stored at 4ºC for up to four days. Values are means of 2 replicates, 5 observations each. Columns with the same letter are not significantly different (α= 0.05). 1= Complete crumbling, 5= Completely pliable. For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, Su= Sumac bran, and A=Additives.

Phenol levels and ABTS antioxidant activity

Treatments containing additives had significantly lower amounts of extractable phenols than their counterpart without additives (Table XXI, appendix C). The amount of phenolic compounds was reduced by up to 15%. The reduction in extractability of phenols was not consistent with a reduction in ABTS antioxidant activity. Aside from tortillas containing 10% Sumac bran, antioxidant potential was not significantly changed by the antistaling formula (Table XXII, appendix C). When additives were present, tortillas containing Sumac bran had even lower amounts of phenols than Black bran tortillas. Tannins combine with proteins and other polymers. Starch degradation by the enzyme could enhance the formation of protein-tannin complexes with reduced extractability. This may partly explain the reduction in extractability of phenols and antioxidant potential.

Table XXI. Phenol levels (mg GAE/g) of corn tortillas containing sorghum bran with and without additives. Values are means of 2 replicates, 3 observations each. Means followed by the same letter are not significantly different (α= 0.05). GAE= Gallic acid equivalents. For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, and Su= Sumac bran.

Treatment	Without additives	With additives
Ctrl	2.4 ± 0.2^{b}	2.1 ± 0.0^{a}
5Bl	3.1 ± 0.1^{d}	2.9 ± 0.1^{c}
10Bl	4.3 ± 0.1^{g}	3.9 ± 0.6^{f}
5Su	3.9 ± 0.0^{f}	3.5 ± 0.1^{e}
10Su	5.5 ± 0.1^{i}	4.9 ± 0.1^{h}

Table XXII. ABTS antioxidant activity (µmol TE/g) of corn tortillas containing sorghum bran with and without additives. Values are means of 2 replicates, 3 observations each. Means followed by the same letter are not significantly different (α= 0.05). TE= Trolox equivalents. For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, and Su= Sumac bran.

Treatment	Without additives	With additives
Ctrl	15.1 ± 0.9 ^{a}	14.5 ± 0.5 ^{a}
5Bl	33.1 ± 0.9 ^{b}	33.2 ± 0.2 ^{b}
10Bl	50.2 ± 0.5 ^{d}	48.6 ± 0.3 ^{d}
5Su	38.2 ± 1.0 ^{c}	37.3 ± 1.5 ^{c}
10Su	61.0 ± 0.9 ^{f}	58.5 ± 3.3 ^{e}

Tortilla chips with sorghum bran

Moisture

Tortilla chips moisture content ranged from 2.3 to 2.5% (Table XXIII). No significant differences were found among treatments; which was expected since no significant differences were found in tortilla moisture prior to frying (Appendix D).

The final moisture content in the fried chip should be less than 3% to ensure a crisp texture (Rooney and Serna-Saldivar 1987). Higher moisture contents result in tough, chewy texture. Moisture of tortilla chips with and with out sorghum bran was below 3%, which indicates that 60 s was a good frying time irregardless of the amount and type of sorghum bran added.

Fat content

Tortilla chip fat content after 60 s of frying ranged from 22.6 to 24.9% (d.b.) (Table XXIII). According to Lee (1991) tortilla chips vary in oil content from 21 to 34% depending on corn variety, cooking processes, grinding conditions, baking time, cooling time, etc. Just a slight difference in fat content was found between treatments containing sorghum bran and the control, which suggests that bran addition did not have an effect in theamount of oil absorbed by the chips during frying. This is contradictory since bran affects tortilla structure, and changes in structure affect the mechanism of oil absorption (Moreira et al. 1999).

Dietary fiber

Tortilla chip fiber was estimated using the dietary fiber values correspondent to the fractions of nixtamalized corn flour (NCF) and sorghum bran present in each treatment. A fiber content of 10% was assumed for NCF, 38% for Sumac and 52% for Black bran. One serving (30 g) of tortillas chips containing sorghum bran at 5% had a dietary fiber content of 2.6 g and qualifies as a “good source of fiber”. As in tortillas, dietary fiber content can be increased by up to 40% adding sorghum bran.

Color

As with table tortillas, tortilla chips containing sorghum bran had different appearance than the control (Figure 31). Purple tortilla chips were produced when Black sorghum bran was added whereas Sumac bran utilization yielded reddish-brown chips.

Instrumental color measurements also reflected the change in color caused by sorghum bran addition (Fig 32, Appendix D). All parameters were affected by sorghum bran level and type. Tortilla chips containing sorghum bran had lower L* values than the control, which indicates that they were darker. As in tortillas, tortilla chip darkness increased as the amount of bran added increased. For the same level of addition Black bran yielded darker tortillas than Sumac bran.

Sorghum bran addition produced chips with a higher red hue (a* values) than the control (Figure 32). The largest a* value was for tortilla chips containing 10% Sumac bran. Less yellow tortilla chips were produced when sorghum bran was utilized (Figure 32). Within bran type the higher the level of addition the lower the b* value. Chips containing Black sorghum bran had the lowest values. The same trend was observed for table tortillas.

Sorghum bran naturally gives tortilla chips a dark color. Colorful tortilla chips could be attractive to the consumers. Chips made from blue corn, and sweet and blue potato are already available in specialty foods market which suggests that chips produced with sorghum bran could have a niche market.

Table XXIII. Moisture content and crude fat content of tortilla chips containing sorghum bran. Values are means of 2 replicates, 3 observations each. Means in the same column followed by the same letter are not significantly different (α= 0.05).For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, and Su= Sumac bran.

Treatment	Moisture	Crude Fat (%)
Ctrl	2.5 ^{a}	23.9
5Bl	2.5 ^{a}	23.4
10Bl	2.4 ^{a}	22.6
5Su	2.3 ^{a}	23.0
10Su	2.3 ^{a}	24.9

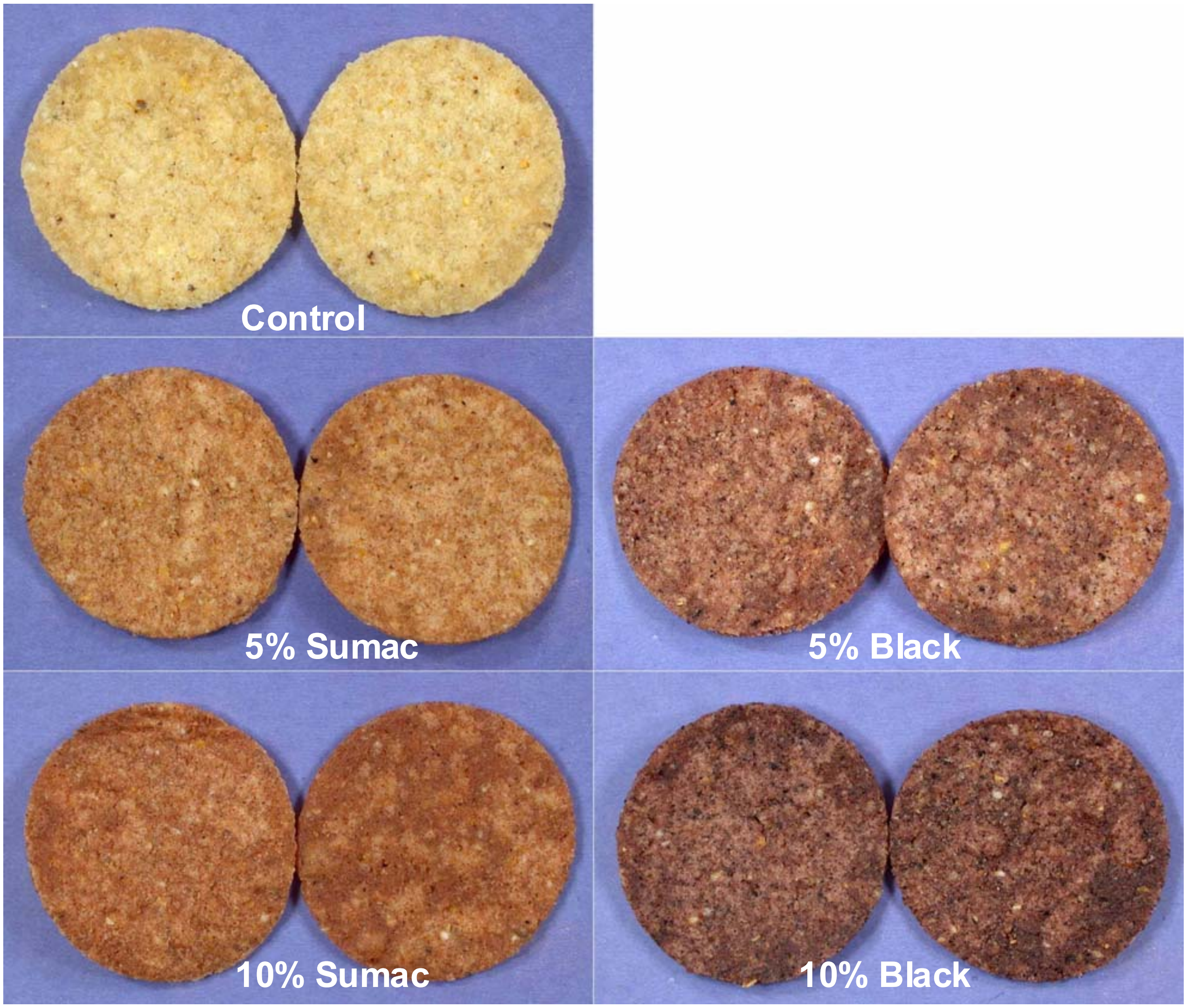

Figure 31. Appearance of tortilla chips containing different levels and type of sorghum bran

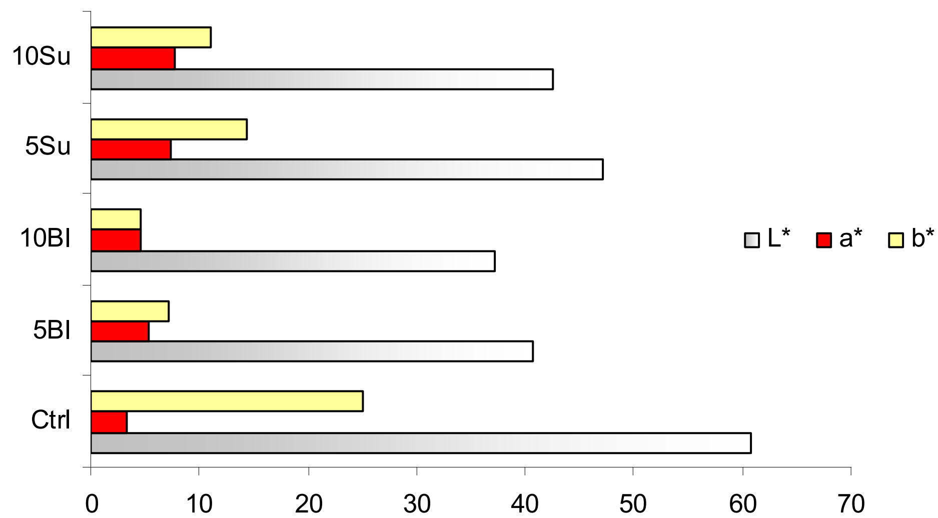

Figure 32. Color of tortilla chips containing sorghum bran. L* indicates lightness, a* indicates hue on a green (-) to red (+) axis, and b* indicates hue on a blue (-) to yellow (+) axis. Values are means of 4 replicates, 3 observations each. For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, and Su= Sumac bran.

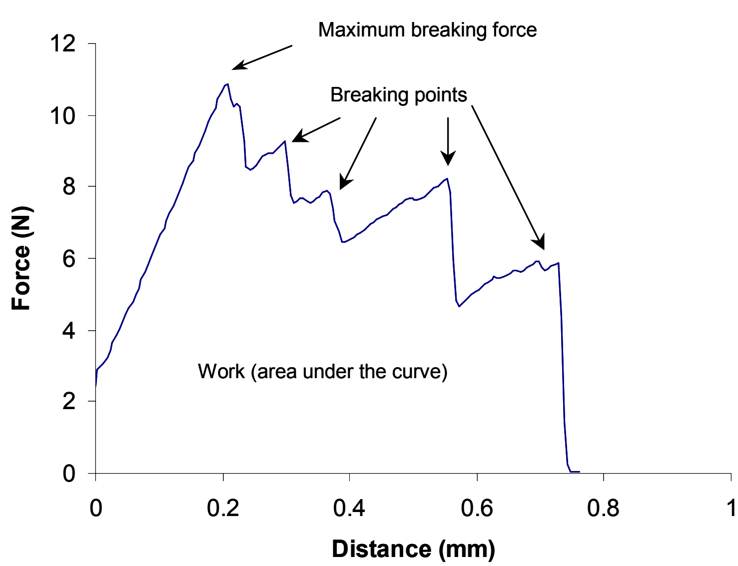

Figure 33. Typical fracturability curve for a tortilla chip.

Texture

Fracturability test

A typical curve for tortilla chip fracturability test is shown in Fig. 33. The first peak force indicates the initial fracture of the sample. The series of minor fractures that appear after the initial fracture indicate that the chip sample was composed of various layers.

In general, the method utilized to evaluate texture was not sensitive to texture differences between treatments. No significant differences were found among treatments in terms of maximum breaking force (Table XXIV). For the work required to break tortilla chips (area under the curve during texture evaluation), a slight difference was observed. Chips containing 10% black sorghum bran required more work to break than the other treatments (Table XXIV). Work to break chips was not significantly changed by the level of bran addition.

The results in table XXIV show that for all treatments there was a large variation in both the maximum rupture force and the work required to break the tortilla chip. The standard deviation was above 26% for the work required to break the chips and above 16% for the maximum breaking force. These results suggest that the texture analyzer fracturability test was not adequate to assess texture differences of the tortilla chips.

Regardless of the treatment, chips were hard and shattered when subjected to the force in compression test. In general not many breaking points were observed, but when pillows were present the number of breaking points and consequently the work required to break the chip increased. This was likely the cause of inconsistency among replicates.

According to McDonough et al. (1993), after extensive frying (1 to 2 min) tortilla chips have a though, hard texture, and when broken snap cleanly and smoothly. Hence tortillas containing sorghum bran could have been over-fried, up to the point where texture differences were not longer noticeable.

In attempts to test if the variability was caused by the bite size of the round tortilla chips (1 ½ in. diameter), the texture of chips with a diameter of 2 ¼ in. was measured. The force and work values obtained had similar variation, indicating that the diameter of the chip was not causing the variability (Table XXV).

Table XXIV. Maximum breaking force (N) and work (N/mm) required to break tortilla chips (round, 1 ½ in. diameter). Values are means of 4 replicates, 30 observations each. Columns followed by the same letter are not significantly different (α= 0.05). For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, and Su= Sumac bran.

Treatment	Maximum breaking force (N)	Work to rupture (N/mm)
Ctrl	11.1 ± 2.1 [a]	9.1 ± 2.7 [a]
5Bl	11.1 ± 2.0 [a]	9.8 ± 3.0 [a,b]
10Bl	11.4 ± 2.0 [a]	10.4 ± 3.2 [b]
5Su	11.1 ± 1.9 [a]	9.4 ± 2.9 [a]
10Su	10.6 ± 1.7 [a]	9.5 ± 2.5 [a]

Table XXV. Maximum breaking force (N) and work (N/mm) required to break tortilla chips (round, 2 ¼ in. diameter). Values are means of 30 observations. Columns followed by the same letter are not significantly different (α= 0.05). For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, and Su= Sumac bran.

Treatment	Maximum breaking force (N)	Work to rupture (N/mm)
Ctrl	14.8 ± 2.7 [a]	25.6 ± 9.5 [a]
5Bl	14.1 ± 2.2 [a]	25.9 ± 7.7 [a]
10Bl	13.3 ± 1.6 [a]	25.6 ± 6.5 [a]
5Su	13.5 ± 1.9 [a]	25.0 ± 8.4 [a]
10Su	13.5 ± 2.8 [a]	26.0 ± 8.6 [a]

Breakage susceptibility test

The more friable chips were the ones containing Sumac sorghum bran, especially the ones with 10% bran added (10Su) (Table XXVI). They produced more fines and less large broken pieces than the other treatments; which suggest that they could be more susceptible to breakage during packaging and handling.

Aside from chips with 10% Sumac bran added, breakage susceptibility values for tortilla chips containing sorghum bran were not significantly different from the control, implying that sorghum bran did not affect the texture of tortilla chips. This is contradictory because sorghum bran interferes with the tortilla matrix, and it could be expected to affect tortilla chip structure as well. Bran particulates could interrupt the continuous phase formed by starch, protein and lipids yielding some holes for steam to escape, which in turn would prevent air cell and tunnel formation. Without steam available to expand as pressure builds, the chip would lack of an expanded structure. Hence a more dense product would be obtained, and dense products have less fracture points and are less susceptible to breakage (Quintero Fuentes et al. 1999).

In general, it was observed that the chips produced had a compact structure (even the control), required high force and work to break and had a low susceptibility to breakage due to lack of fracture points in the structure.

Table XXVI. Breakage susceptibility data from tortilla chips with different type and levels of sorghum bran added. Values are means of 4 replicates, 3 observations each. Columns followed by the same letter are not significantly different (α= 0.05). For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, and Su= Sumac bran.

Treatment	Broken pieces (total weight %) [1]			
	Large[2]	Intermediate[3]	Small[4]	Fines[5]
Ctrl	86.5 ± 0.1 [b,c]	8.0 ± 0.1 [a]	5.1 ± 0.0 [a]	0.5 ± 0.0 [a]
5Bl	87.0 ± 0.2 [c]	6.9 ± 0.1 [a]	5.7 ± 0.1 [a]	0.4 ± 0.0 [a]
10Bl	80.2 ± 0.1 [b,c]	8.1 ± 0.1 [a]	10.9 ± 0.1 [a,b]	0.7 ± 0.0 [a]
5Su	76.3 ± 0.1 [a,b]	13.2 ± 0.1 [a,b]	10.0 ± 0.1 [a,b]	0.5 ± 0.0 [a]
10Su	68.5 ± 0.1 [a]	17.7 ± 0.1 [b]	13.0 ± 0.1 [b]	0.8 ± 0.0 [a]

[1] Weight % from 10 whole chips

[2] Large pieces are 95-100% the size of an unbroken chip

[3] Intermediate pieces are 50-95% the size of an unbroken chip

[4] Small pieces are 5-50% the size of an unbroken chip

[5] Fines are less than 5% the size of an unbroken chip

Phenol levels and ABTS antioxidant activity

The phenolic contents were expressed as milligrams of gallic acid equivalents per gram of defatted material (d.b.). Results followed the same trend as table tortillas. Tortilla chips containing sorghum bran had significantly higher amounts of phenols than the control (Appendix D, Fig. 34), and extractable phenols increased as the level of bran addition increased. The treatment with 10% Sumac bran (10Su) had three times more phenols than the control.

The antioxidant activity of the tortilla chips is given in Figure 35. Antioxidant potential was expressed as micromoles of trolox equivalents per gram of defatted material (db). Significant differences were found among the ABTS antioxidant activity of tortilla chips. Tortilla chips containing either Black or Sumac bran had significantly higher antioxidant activity than control chips (Appendix D, Fig. 35); which indicates that some of the bran antioxidant activity was retained through tortilla chip processing. Chips containing 10% Sumac bran (10 Su) had four times the antioxidant potential of the control. The same trend was observed for table tortillas.

Regardless of the level of addition, tortilla chips containing Sumac bran had higher antioxidant values than their counterpart containing Black sorghum bran (Appendix D, Fig. 35). As explained before, it was likely due to the presence of tannins, which have potent antioxidant activities.

Assuming that the ORAC value of sorghum products is 3-4 times higher than the ABTS value (Awika et al. 2003), one serving (30 g) of tortilla chips containing 5% Sumac bran would have an antioxidant activity equivalent to that of 20 g of blueberries (62.2 μmol TE/g fresh weight, Wu et al. 2004).

Assayable phenols and ABTS antioxidant activity correlated strongly with each other. For tortilla chips the correlation was even higher than for table tortillas. About 97% of the variation in chip antioxidant activity could be explained by the amount of phenols (Fig. 36). Tortilla chips data corroborate that extractable phenols are a good predictor of in vitro antioxidant activity.

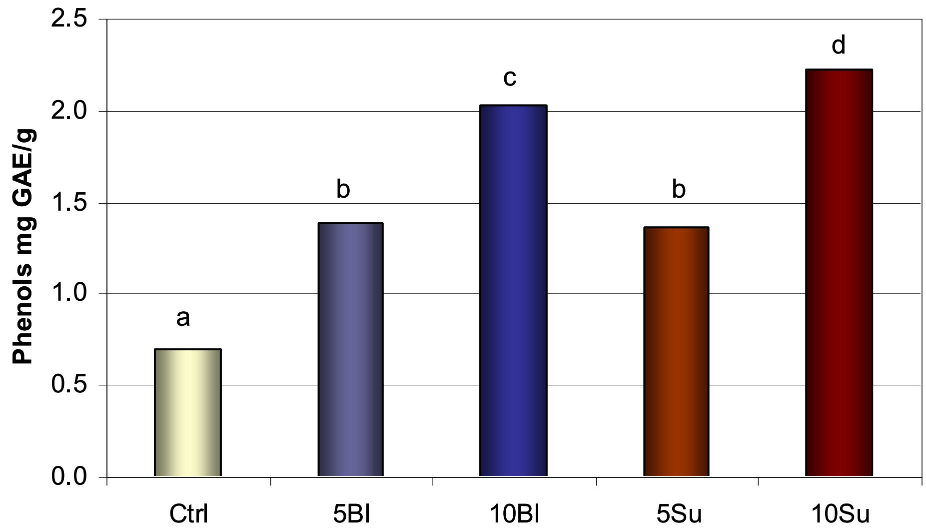

Figure 34. Phenol levels (mg GAE/g db of defatted material) of corn tortillas containing sorghum bran. Values are means of 2 replicates, 3 observations each. Columns with the same letter are not significantly different (α= 0.05). GAE= Gallic acid equivalents. For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, and Su= Sumac bran.

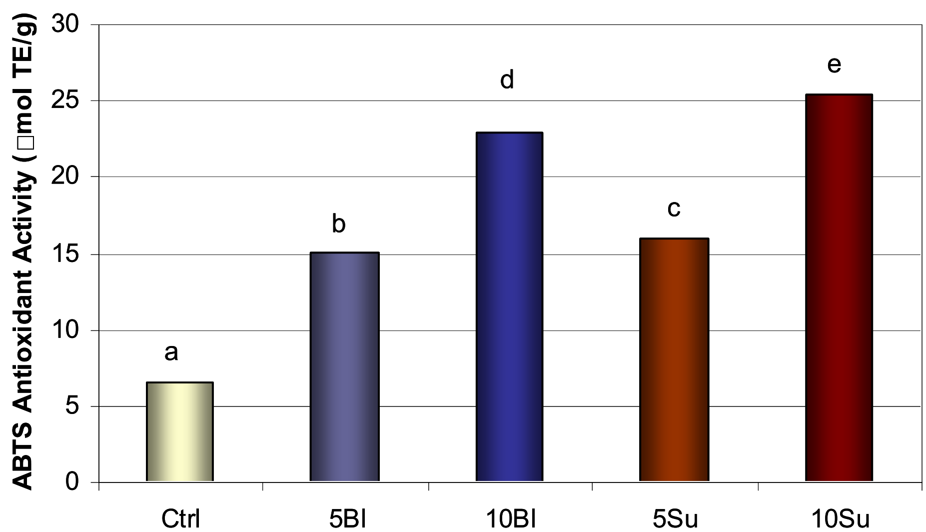

Figure 35. ABTS antioxidant activity (μmol TE/g db of defatted material) of tortilla chips containing sorghum bran. Values are means of 2 replicates, 3 observations each. Columns with the same letter are not significantly different (α= 0.05). TE= Trolox equivalents. For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, and Su= Sumac bran.

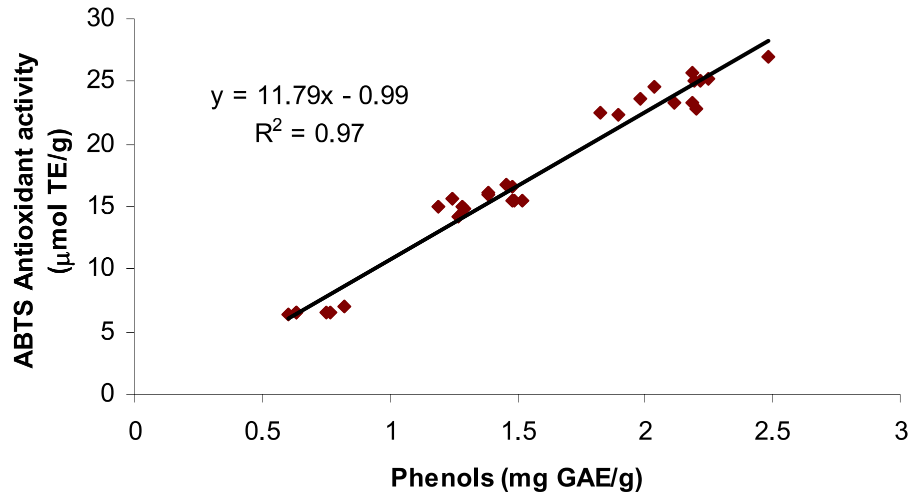

Figure 36. Correlation between ABTS antioxidant activity and level of phenols in tortilla chips containing sorghum bran.

Phenols and ABTS antioxidant activity of table tortillas vs. tortilla chips

The amount of extractible phenolic compounds in tortilla chips was at least 28% of that in table tortillas (Table XXVII). The retention in extractability of phenols was lower for the control than for tortilla chips containing sumac bran (Table XXVII). Among tortilla chips containing sorghum bran, Sumac treatments had the lower retention values. Data suggest that the steps involved in tortilla chip processing caused a further reduction in phenol extractability.

The reduction in the amount of assayable phenols was consistent with a reduction in the antioxidant potential (Table XXVIII). The antioxidant activity in tortilla chips was about 45% of that in table tortillas. Reduced extractability of major contributors to antioxidant activity may partly explain the reduced levels of antioxidants found.

Table XXVII. Phenol levels (mg GAE/g) of table tortillas and tortilla chips containing sorghum bran. For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, and Su= Sumac bran.

Treatment	Tortilla	Chips	Retention (%)
Ctrl	2.5 ± 0.2	0.7 ± 0.1	28
5Bl	3.1 ± 0.1	1.4 ± 0.1	45
10Bl	4.3 ± 0.1	2.0 ± 0.2	48
5Su	3.9 ± 0.0	1.4 ± 0.1	34
10Su	5.5 ± 0.1	2.2 ± 0.1	40

Table XXVIII. ABTS antioxidant activity (μmol TE/g) of tortillas and tortilla chips containing sorghum bran. For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, and Su= Sumac bran.

Treatment	Tortilla	Chips	Retention (%)
Ctrl	15.2 ± 0.5	6.6 ± 0.2	43
5Bl	33.1 ± 0.9	15.1 ± 0.5	45
10Bl	50.2 ± 0.5	23.0 ± 0.5	46
5Su	38.2 ± 1.0	16.0 ± 0.6	42
10Su	61.0 ± 0.9	25.4 ± 0.8	42

Table XXIX. Sensory panel results for tortilla chips containing different levels of Black and Sumac sorghum bran. For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, and Su= Sumac bran.

Treatment	Appearance	Texture	Flavor
Ctrl	7.7 ± 0.6^{c}	7.1 ± 1.1^{a}	6.9 ± 1.1^{a}
5Bl	$6.0 \pm 1.9^{a,b}$	6.7 ± 1.8^{a}	7.0 ± 1.5^{a}
10Bl	5.7 ± 2.2^{a}	6.4 ± 1.7^{a}	6.8 ± 1.2^{a}
5Su	6.4 ± 1.5^{b}	6.5 ± 1.6^{a}	6.4 ± 1.4^{a}
10Su	$6.2 \pm 1.7^{a,b}$	6.5 ± 1.6^{a}	6.5 ± 1.5^{a}

Sensory evaluation

Tortilla chips were evaluated for appearance, texture and flavor by thirty untrained panelists using a 9 point hedonic scale, where 1 was defined as “dislike extremely”, 5 as “neither like or dislike” and 9 as “like extremely”.

Scores ranged from 5.7 to 7.7 which indicated that tortilla chips were liked. Addition of sorghum bran produced minor changes in the texture and flavor of chips, but a significant decrease in appearance acceptability was observed (Table XXIX). Control chips appearance was preferred over tortilla chips containing sorghum bran. Chips produced with sorghum bran did not have the characteristic color of chips prepared from white or yellow corn, and while some panelists found them visually appealing, others rejected them. This suggests that color has high influence on chips acceptability.

The inability to detect significant differences among chips containing 5% or 10% sorghum bran suggests that sorghum bran could be utilized at up to 10% without causing major changes in the organoleptic properties of tortilla chips.

As the instrumental analysis, the sensory evaluation of tortilla chips texture indicated that chips containing sorghum bran were not significantly different from the control (Table XXIV). In regards to texture acceptability, opinions were divided. While some panelist reported that chips were hard to bite, other found them acceptable. The perception of toughness may be partly explained by chip thickness. The chips produced were thicker than the ones available in the market. Nevertheless this characteristic could be of advantage for applications such as dipping, where chips that hold together when scooping dips are desired.

Sorghum bran from specialty sorghums could be utilized to produce colorful chips that are visually appealing to health conscious consumers who are familiar with dark colored foods.

SUMMARY AND CONCLUSIONS

Bran addition interfered in tortilla structure and reduced tortilla strength. A reduction in the strength of the continuous phase resulted in low rupture force and undesirable rollability and pliability scores. The detrimental effect of bran addition was stronger for Black bran. When compared with Sumac bran, Black sorghum bran was found to be coarser; apparently the extent of structure damage is greatly affected by particle size. Carboxymethylcellulose, guar gum and maltogenic alpha-amylase strengthened tortilla structure and improved tortilla texture only when Sumac bran was used. Different levels of the additives evaluated, or other additives may have to be included to prevent black sorghum bran tortillas from crumbling. Additives also increased tortilla puffiness and appearance making the product more attractive to consumers.

Although tortilla chips containing sorghum bran were expected to have different texture than the control, no significant differences were found. Over- frying could have altered tortilla chip structure up to the point where texture differences among treatments were no longer noticeable. Optimal frying time needs to be determined.

Sumac bran yielded larger amounts of phenols and antioxidant activity than Black bran. Tannins are responsible for their high antioxidant activity. Levels of phenols and antioxidant potential increased with increased bran. When processed into table tortillas and tortilla chips, the sorghum fractions retained at least one third of their original antioxidant activity. Good retention of antioxidant activity in processed products suggests that sorghum bran could be a valuable ingredient in the development of functional foods.

Antioxidant activity can be increased up to four times by adding sorghum bran. One serving of tortilla (55 g) containing 5% Sumac bran has an antioxidant activity equivalent to that of 60 g of blueberries and is a “good source of fiber” (3.2 g), whereas one serving (30 g) of tortilla chips with 5% Sumac bran have an antioxidant activity equivalent to that of 20 g of blueberries and also qualifies as a “good source of fiber”. Food products made with specialty sorghum brans could be a good source of fiber and antioxidants in diets.

Specialty sorghum brans produced table tortillas and tortilla chips with increased levels of dietary fiber and antioxidants without adversely affecting other sensory properties. Bran addition caused no significant differences in ratings for any attribute aside from appearance. Sorghum bran naturally gives tortilla and tortilla chips a dark color that could be appealing to health conscious consumers who are familiar with dark colored foods. The data demonstrate that brans from specialty sorghums have the potential to be a valuable ingredient in functional foods.

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APPENDIX A

TORTILLAS WITH SORGHUM BRAN

Table A-1. Moisture content (%) of masa. Values are means of 2 replicates, 3 observations each. Means in the same column followed by the same letter are not significantly different (α= 0.05). For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, and Su= Sumac bran.

Treatment	Moisture %
Ctrl	60.1 ± 0.0 ^{a}
5Bl	59.1 ± 0.0 ^{a}
10Bl	58.8 ± 0.0 ^{a}
5Su	59.2 ± 0.0 ^{a}
10Su	58.9 ± 0.0 ^{a}

Table A-2. Color of corn tortillas containing sorghum bran, where L* indicates lightness, a* indicates hue on a green (-) to red (+) axis, and b* indicates hue on a blue (-) to yellow (+) axis. Values are means of 2 replicates, 3 observations each. Means in the same column followed by the same letter are not significantly different (α= 0.05). For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, and Su= Sumac bran.

Treatment	L*	a*	b*
Ctrl	77.6 ± 0.7 ^{e}	0.5 ± 0.3 ^{a}	21.8 ± 0.7 ^{d}
5Bl	43.3 ± 0.9 ^{b}	8.6 ± 0.2 ^{b}	7.5 ± 0.4 ^{b}
10Bl	36.7 ± 0.6 ^{a}	8.8 ± 0.2 ^{b}	6.8 ± 0.2 ^{a}
5Su	54.1 ± 0.7 ^{d}	11.4 ± 0.5 ^{c}	15.7 ± 0.2 ^{d}
10Su	47.6 ± 0.6 ^{c}	11.7 ± 0.1 ^{c}	14.6 ± 0.2 ^{c}

Table A-3. Rupture force (N) of corn tortillas containing sorghum bran stored at 4ºC. Values are means of 2 replicates, 10 observations each. Means in the same column followed by the same letter are not significantly different (α= 0.05). For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, and Su= Sumac bran.

Treatment	Storage Time (days)		
	0	1	4
Ctrl	4.6 ± 0.7 ^{a}	10.3 ± 0.5 ^{c}	12.1 ± 0.4 ^{c}
5Bl	5.1 ± 0.4 ^{a,b}	9.8 ± 0.7 ^{a}	10.6 ± 0.5 ^{a}
10Bl	5.6 ± 0.4 ^{c}	10.1 ± 0.6 ^{a,b}	10.7 ± 0.8 ^{a}
5Su	5.2 ± 0.4 ^{b,c}	9.8 ± 0.6 ^{a}	11.5 ± 0.7 ^{b}
10Su	5.0 ± 0.5 ^{a,b}	10.5 ± 0.6 ^{c}	11.3 ± 0.7 ^{b}

Table A-4. Modulus of deformation (N/mm) of corn tortillas containing sorghum bran stored at 4ºC. Values are means of 2 replicates, 10 observations each. Means in the same column followed by the same letter are not significantly different (α= 0.05). For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, and Su= Sumac bran.

Treatment	Storage Time (days)		
	0	1	4
Ctrl	1.8 ± 0.3 ^{a}	2.9 ± 0.2 ^{c}	3.3 ± 0.2 ^{b,c}
5Bl	1.8 ± 0.3 ^{a}	2.4 ± 0.2 ^{b}	3.1 ± 0.4 ^{a,b}
10Bl	1.6 ± 0.2 ^{a}	1.9 ± 0.3 ^{a}	2.8 ± 0.4 ^{a}
5Su	1.7 ± 0.3 ^{a}	2.6 ± 0.3 ^{b}	3.5 ± 0.5 ^{c}
10Su	1.7 ± 0.3 ^{a}	2.5 ± 0.3 ^{b}	3.5 ± 0.6 ^{c}

Table A-5. Rollability score of corn tortillas containing sorghum bran stored at 4ºC. Values are means of 2 replicates, 5 observations each. Means in the same column followed by the same letter are not significantly different (α= 0.05). For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, and Su= Sumac bran.

Treatment	Storage Time (days)		
	0	1	4
Ctrl	5.0 ± 0.0 ^{a}	4.6 ± 0.3 ^{c}	3.3 ± 0.3 ^{c}
5Bl	5.0 ± 0.0 ^{a}	4.0 ± 0.3 ^{b}	2.5 ± 0.2 ^{b}
10Bl	5.0 ± 0.0 ^{a}	3.6 ± 0.5 ^{a}	2.1 ± 0.2 ^{a}
5Su	5.0 ± 0.0 ^{a}	4.3 ± 0.3 ^{b,c}	2.7 ± 0.3 ^{b}
10Su	5.0 ± 0.0 ^{a}	4.1 ± 0.4 ^{b}	2.4 ± 0.3 ^{b}

Table A-6. Pliability score of corn tortillas containing sorghum bran stored at 4ºC. Values are means of 2 replicates, 5 observations each. Means in the same column followed by the same letter are not significantly different (α= 0.05). For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, and Su= Sumac bran.

Treatment	Storage Time (days)		
	0	1	4
Ctrl	4.7 ± 0.1 ^{b,c}	2.4 ± 0.2 ^{b}	2.1 ± 0.2 ^{c}
5Bl	4.6 ± 0.1 ^{a,b,c}	2.3 ± 0.3 ^{b}	1.7 ± 0.3 ^{a,b}
10Bl	4.4 ± 0.3 ^{a}	1.9 ± 0.1 ^{a}	1.5 ± 0.2 ^{a}
5Su	4.9 ± 0.2 ^{c}	2.3 ± 0.2 ^{b}	2.1 ± 0.2 ^{c}
10Su	4.5 ± 0.3 ^{a,b}	2.2 ±0.2 ^{b}	1.9 ± 0.2 ^{b,c}

Table A-7. Phenol levels (mg GAE/g, db) of corn tortillas containing sorghum bran. Values are means of 2 replicates, 3 observations each. Means in the same column followed by the same letter are not significantly different (α= 0.05). GAE= Gallic acid equivalents. For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, and Su= Sumac bran.

Treatment	Phenols mg GAE/g
Ctrl	2.5 ± 0.2 [a]
5Bl	3.1 ± 0.1 [b]
10Bl	4.3 ± 0.1 [d]
5Su	3.9 ± 0.0 [c]
10Su	5.5 ± 0.1 [e]

Table A-8. ABTS Antioxidant activity (μmol TE/g, db) of corn tortillas containing sorghum bran. Values are means of 2 replicates, 3 observations each. Means in the same column followed by the same letter are not significantly different (α= 0.05). TE= Trolox equivalents. For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, and Su= Sumac bran.

Treatment	Antioxidant activity µmol TE/g
Ctrl	15.2 ± 0.5 [a]
5Bl	33.1 ± 0.9 [b]
10Bl	50.2 ± 0.5 [d]
5Su	38.2 ± 1.0 [c]
10Su	61.0 ± 0.9 [e]

Table A-9. Phenol levels (mg GAE/g, db) before processing. Values are means of 2 replicates, 2 observations each. GAE= Gallic acid equivalents. For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, and Su= Sumac bran.

Treatment	Dry Ingredients	Masa		
		Fresh	Dry	Freeze-dried
Ctrl	3.4	2.0	3.6	3.0
5Bl	4.3	3.1	4.0	3.9
10Bl	5.1	4.0	4.8	4.8
5Su	5.7	3.6	5.1	4.8
10Su	9.0	5.4	6.6	7.1

Table A-10. ABTS Antioxidant activity (μmol TE/g, db) before processing. Values are means of 2 replicates, 2 observations each. Means in the same row followed by the same letter are not significantly different (α= 0.05). TE= Trolox equivalents. For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, and Su= Sumac bran.

Treatment	Dry Ingredients	Masa		
		Fresh	Dry	Freeze-dried
Ctrl	11.4	15.8	11.2	13.4
5Bl	32.0	34.2	23.5	32.7
10Bl	48.7	49.4	38.1	48.0
5Su	50.6	39.7	28.2	42.5
10Su	78.2	62.0	47.0	68.3

APPENDIX B

TORTILLAS WITH SORGHUM BRAN AND THE ANTISTALING FORMULA

Table B-1. Moisture content (%) of masa. Values are means of 2 replicates, 3 observations each. Means in the same column followed by the same letter are not significantly different (α= 0.05). For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, Su= Sumac bran, and A= Additives.

Treatment	Moisture (%)
Ctrl	60.2 ± 0.0 ^{b}
5Bl+A	59.9 ± 0.0 ^{b}
10Bl+A	59.8 ± 0.0 ^{b}
5Su+A	59.6 ± 0.0 ^{b}
10Su+A	59.2 ± 0.0 ^{a}
Ctrl+A	59.8 ± 0.0 ^{b}

Table B-2. Color of corn tortillas containing sorghum bran and the antistaling formula, where L* indicates lightness, a* indicates hue on a green (-) to red (+) axis, and b* indicates hue on a blue (-) to yellow (+) axis. Values are means of 2 replicates, 3 observations each. Means in the same column followed by the same letter are not significantly different (α= 0.05). For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, Su= Sumac bran, and A= Additives.

Treatment	L*	a*	b*
Ctrl	77.6 ± 0.7 ^{e}	0.5 ± 0.3 ^{a}	21.8 ± 0.7 ^{f}
5Bl+A	46.6 ± 1.1 ^{b}	8.4 ± 0.1 ^{b}	8.2 ± 0.3 ^{b}
10Bl+A	39.6 ± 1.2 ^{a}	8.5 ± 0.2 ^{b}	7.1 ± 0.5 ^{a}
5Su+A	55.4 ± 0.6 ^{d}	11.0 ± 0.5 ^{c}	15.8 ± 0.4 ^{d}
10Su+A	49.9 ± 0.8 ^{c}	11.4 ± 0.3 ^{c}	15.0 ± 0.4 ^{c}
Ctrl+A	79.0 ± 0.4 ^{f}	0.4 ± 0.1 ^{a}	20.2 ± 0.6 ^{e}

Table B-3. Rupture force (N) of corn tortillas containing sorghum bran and the antistaling formula, stored at 4ºC. Values are means of 2 replicates, 10 observations each. Means in the same column followed by the same letter are not significantly different (α= 0.05). For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, Su= Sumac bran, and A= Additives.

Treatment	Storage Time (days)		
	0	1	4
Ctrl	4.6 ± 0.7 ^{e}	10.3 ± 0.5 ^{d}	12.1 ± 0.4 ^{d}
5Bl+A	3.6 ± 0.3 ^{a}	7.8 ± 0.3 ^{a}	9.2 ± 0.4 ^{a}
10Bl+A	3.8 ± 0.5 ^{a,b,c}	8.1 ± 0.4 ^{a}	9.9 ± 0.5 ^{b}
5Su+A	3.7 ± 0.2 ^{a,b}	8.5 ± 0.5 ^{b}	9.7 ± 0.7 ^{b}
10Su+A	4.0 ± 0.4 ^{b,c}	8.9 ± 0.5 ^{c}	10.7 ± 0.4 ^{c}
Ctrl+A	4.1 ± 0.4 ^{d}	8.9 ± 0.7 ^{b,c}	9.7 ± 0.7 ^{b}

Table B-4. Modulus of deformation (N/mm) of corn tortillas containing sorghum bran and the antistaling formula, stored at 4ºC. Values are means of 2 replicates, 10 observations each. Means in the same column followed by the same letter are not significantly different (α= 0.05). For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, Su= Sumac bran, and A= Additives.

Treatment	Storage Time (days)		
	0	1	4
Ctrl	1.8 ± 0.3 ^{b,c}	2.9 ± 0.2 ^{d}	3.3 ± 0.2 ^{d}
5Bl+A	1.6 ± 0.2 ^{b,c}	2.1 ± 0.2 ^{b}	2.1 ± 0.2 ^{b}
10Bl+A	1.4 ± 0.3 ^{a}	1.6 ± 0.3 ^{a}	1.9 ± 0.3 ^{a}
5Su+A	1.7 ± 0.3 ^{b,c}	2.3 ± 0.2 ^{b}	2.5 ± 0.4 ^{c}
10Su+A	1.6 ± 0.4 ^{a,b}	2.2 ± 0.3 ^{b}	2.5 ± 0.4 ^{c}
Ctrl+A	1.8 ± 0.4 ^{c}	2.5 ± 0.3 ^{c}	2.7 ± 0.3 ^{c}

Table B-5. Rollability score of corn tortillas containing sorghum bran and the antistaling formula, stored at 4ºC. Values are means of 2 replicates, 5 observations each. Means in the same column followed by the same letter are not significantly different (α= 0.05). For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, Su= Sumac bran, and A= Additives.

Treatment	**Storage Time (days)**		
	0	**1**	**4**
Ctrl	5.0 ± 0.0 ^{a}	4.6 ± 0.3 ^{c}	3.3 ± 0.3 ^{b}
5Bl+A	5.0 ± 0.0 ^{a}	3.6 ± 0.3 ^{b}	2.8 ± 0.3 ^{b}
10Bl+A	5.0 ± 0.0 ^{a}	3.1 ± 0.3 ^{a}	1.9 ± 0.2 ^{a}
5Su+A	5.0 ± 0.0 ^{a}	4.6 ± 0.2 ^{c,d}	3.3 ± 0.5 ^{b}
10Su+A	5.0 ± 0.0 ^{a}	4.3 ± 0.3 ^{c}	3.3 ± 0.3 ^{b}
Ctrl+A	5.0 ± 0.0 ^{a}	5.0 ± 0.1 ^{d}	4.3 ± 0.3 ^{c}

Table B-6. Pliability score of corn tortillas containing sorghum bran and the antistaling formula, stored at 4ºC. Values are means of 2 replicates, 5 observations each. Means in the same column followed by the same letter are not significantly different (α= 0.05). For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, Su= Sumac bran, and A= Additives.

Treatment	**Storage Time (days)**		
	0	**1**	**4**
Ctrl	4.7 ± 0.1 ^{b}	2.4 ± 0.2 ^{b,c}	2.1 ± 0.2 ^{c}
5Bl+A	4.5 ± 0.3 ^{a,b}	2.2 ± 0.3 ^{a,b}	1.8 ± 0.3 ^{b}
10Bl+A	4.3 ± 0.3 ^{a}	2.0 ± 0.2 ^{a}	1.5 ± 0.3 ^{a}
5Su+A	4.6 ± 0.2 ^{b}	2.8 ± 0.3 ^{d}	2.4 ± 0.2 ^{c}
10Su+A	4.5 ± 0.2 ^{a,b}	2.5 ± 0.2 ^{c}	2.2 ± 0.1 ^{c}
Ctrl+A	5.0 ± 0.0 ^{c}	3.5 ± 0.3 ^{e}	2.9 ± 0.2 ^{d}

Table B-7. Phenol levels (mg GAE/g) in corn tortillas containing sorghum bran and additives. Values are means of 2 replicates, 3 observations each. Means in the same column followed by the same letter are not significantly different (α= 0.05). GAE= Gallic acid equivalents. For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, Su= Sumac bran, and A= Additives.

Treatment	Phenols Mg GAE/g
Ctrl	2.3 ± 0.0^{b}
5Bl+A	2.9 ± 0.1^{c}
10Bl+A	3.9 ± 0.1^{e}
5Su+A	3.5 ± 0.1^{d}
10Su+A	4.9 ± 0.1^{f}
Ctrl+A	2.1 ± 0.0^{a}

Table B-8. ABTS Antioxidant activity (μmol TE/g) of corn tortillas containing sorghum bran and additives. Values are means of 2 replicates, 3 observations each. Means in the same column followed by the same letter are not significantly different (α= 0.05). TE= Trolox equivalents. For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, Su= Sumac bran, and A= Additives.

Treatment	Antioxidant activity μmol TE/g
Ctrl	15.5 ± 1.1^{a}
5Bl+A	33.2 ± 0.2^{b}
10Bl+A	48.6 ± 0.3^{d}
5Su+A	37.3 ± 1.5^{c}
10Su+A	58.5 ± 3.2^{e}
Ctrl+A	14.5 ± 0.5^{a}

APPENDIX C

COMPARISON OF TORTILLAS WITH AND WITHOUT ADDITIVES

Table C-1 Color of corn tortillas containing sorghum bran with and without additives. L* indicates lightness, a* indicates hue on a green (-) to red (+) axis, and b* indicates hue on a blue (-) to yellow (+) axis. Values are means of 2 replicates, 3 observations each. Means in the same column followed by the same letter are not significantly different (α= 0.05). For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, Su= Sumac bran, and A= Additives.

Treatment	L*	a*	b*
Ctrl	77.6 ± 0.7 [h]	0.5 ± 0.3 [a]	21.8 ± 0.7 [f]
Ctrl+A	79.0 ± 0.4 [i]	0.4 ± 0.1 [a]	20.2 ± 0.6 [e]
5Bl	43.3 ± 0.9 [c]	8.6 ± 0.2 [b]	7.5 ± 0.4 [a,b]
5Bl+A	46.6 ± 1.1 [d]	8.4 ± 0.1 [b]	8.2 ± 0.3 [b]
10Bl	36.7 ± 0.6 [a]	8.8 ± 0.2 [b]	6.8 ± 0.2 [a]
10Bl+A	39.6 ± 1.2 [b]	8.5 ± 0.2 [b]	7.1 ± 0.5 [a]
5Su	54.1 ± 0.7 [f]	11.4 ± 0.5 [c,d]	15.7 ± 0.2 [d]
5Su+A	55.4 ± 0.6 [g]	11.0 ± 0.5 [d]	15.8 ± 0.4 [d]
10Su	47.6 ± 0.6 [d]	11.7 ± 0.1 [d]	14.6 ± 0.2 [c]
10Su+A	49.9 ± 0.8 [e]	11.4 ± 0.3 [c,d]	15.0 ± 0.4 [c]

Table C-2 Rupture Force (N/mm) of corn tortillas containing sorghum bran, stored at 4ºC. Values are means of 2 replicates, 10 observations each. Means in the same column followed by the same letter are not significantly different (α= 0.05). For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, Su= Sumac bran. For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, Su= Sumac bran, and A= Additives.

Treatment	Storage Time (days)		
	0	1	4
Ctrl	4.6 ± 0.7 [d]	10.3 ± 0.5 [d]	12.1 ± 0.4 [e]
Ctrl+A	4.1 ± 0.4 [c]	8.9 ± 0.7 [b]	9.7 ± 0.7 [b]
5Bl	5.1 ± 0.4 [e]	9.8 ± 0.7 [c]	10.6 ± 0.5 [c]
5Bl+A	3.6 ± 0.4 [a]	7.8 ± 0.5 [a]	9.2 ± 0.5 [a]
10Bl	5.6 ± 0.4 [f]	10.1 ± 0.6 [c,d]	10.7 ± 0.8 [c]
10Bl+A	3.8 ± 0.5 [a,b,c]	8.1 ± 0.4 [a]	9.9 ± 0.5 [b]
5Su	5.2 ± 0.4 [e,f]	9.8 ± 0.6 [c]	11.5 ± 0.7 [d]
5Su+A	3.7 ± 0.2 [a,b]	8.5 ± 0.5 [b]	9.7 ± 0.7 [b]
10Su	5.0 ± 0.5 [d,e]	10.5 ± 0.6 [d]	11.3 ± 0.7 [d]
10Su+A	4.0 ± 0.4 [b,c]	8.9 ± 0.5 [b]	10.7 ± 0.4 [c]

Table C-3 Modulus of deformation (N/mm) of corn tortillas containing sorghum bran, stored at 4ºC. Values are means of 2 replicates, 10 observations each. Means in the same column followed by the same letter are not significantly different (α= 0.05). For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, Su= Sumac bran, and A= Additives.

Treatment	Storage Time (days)		
	0	**1**	**4**
Ctrl	1.8 ± 0.3 ^{b,c}	2.9 ± 0.2 ^{f}	3.3 ± 0.2 ^{e,f}
Ctrl+A	1.8 ± 0.4 ^{c}	2.5 ± 0.3 ^{e}	2.7 ± 0.3 ^{c}
5Bl	1.8 ± 0.3 ^{c}	2.4 ± 0.2 ^{d,e}	3.1 ± 0.4 ^{d,e}
5Bl+A	1.6 ± 0.2 ^{b,c}	2.1 ± 0.3 ^{c}	2.1 ± 0.3 ^{a,b}
10Bl	1.6 ± 0.2 ^{b}	1.9 ± 0.3 ^{b}	2.8 ± 0.4 ^{c,d}
10Bl+A	1.4 ± 0.3 ^{a}	1.6 ± 0.3 ^{a}	1.9 ± 0.3 ^{a}
5Su	1.7 ± 0.3 ^{b,c}	2.6 ± 0.3 ^{e}	3.5 ± 0.5 ^{f}
5Su+A	1.7 ± 0.3 ^{b,c}	2.3 ± 0.2 ^{c,d}	2.5 ± 0.4 ^{b,c}
10Su	1.7 ± 0.2 ^{b,c}	2.5 ± 0.3 ^{e}	3.5 ± 0.6 ^{e,f}
10Su+A	1.6 ± 0.4 ^{b}	2.2 ± 0.3 ^{c}	2.5 ± 0.4 ^{c}

Table C-4 Rollability score of corn tortillas containing sorghum bran stored at 4ºC. Values are means of 2 replicates, 5 observations each. Means in the same column followed by the same letter are not significantly different (α= 0.05). For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, Su= Sumac bran, and A= Additives.

Treatment	Storage Time (days)		
	0	1	4
Ctrl	5.0 ± 0.0 ^{a}	4.6 ± 0.3 ^{d}	3.3 ± 0.3 ^{d}
Ctrl+A	5.0 ± 0.0 ^{a}	5.0 ± 0.1 ^{e}	4.3 ± 0.3 ^{e}
5Bl	5.0 ± 0.0 ^{a}	4.0 ± 0.3 ^{c}	2.5 ± 0.2 ^{b,c}
5Bl+A	5.0 ± 0.0 ^{a}	3.6 ± 0.3 ^{b}	2.8 ± 0.3 ^{c}
10Bl	5.0 ± 0.0 ^{a}	3.6 ± 0.5 ^{b}	2.1 ± 0.2 ^{a,b}
10Bl+A	5.0 ± 0.0 ^{a}	3.1 ± 0.3 ^{a}	1.9 ± 0.2 ^{a}
5Su	5.0 ± 0.0 ^{a}	4.3 ± 0.3 ^{c,d}	2.7 ± 0.3 ^{c}
5Su+A	5.0 ± 0.0 ^{a}	4.6 ± 0.2 ^{d}	3.3 ± 0.5 ^{d}
10Su	5.0 ± 0.0 ^{a}	4.1 ± 0.4 ^{c}	2.4 ± 0.3 ^{b,c}
10Su+A	5.0 ± 0.0 ^{a}	4.3 ± 0.3 ^{c,d}	3.3 ± 0.3 ^{d}

Table C-5 Pliability score of corn tortillas containing sorghum bran stored at 4ºC. Values are means of 2 replicates, 5 observations each. Means in the same column followed by the same letter are not significantly different (α= 0.05). For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, Su= Sumac bran, and A= Additives.

Treatment	Storage Time (days)		
	0	**1**	**4**
Ctrl	4.7 ± 0.1 ^{a,b}	2.4 ± 0.2 ^{c,d}	2.1 ± 0.2 ^{c,d}
Ctrl+A	5.0 ± 0.0 ^{c}	3.5 ± 0.3 ^{f}	2.9 ± 0.2 ^{e}
5Bl	4.6 ± 0.1 ^{a,b}	2.3 ± 0.3 ^{c,f}	1.7 ± 0.3 ^{a,b}
5Bl+A	4.5 ± 0.3 ^{a,b}	2.2 ± 0.3 ^{b,c}	1.8 ± 0.3 ^{b}
10Bl	4.4 ± 0.3 ^{a}	1.9 ± 0.1 ^{a}	1.5 ± 0.2 ^{a}
10Bl+A	4.3 ± 0.3 ^{a}	2.0 ± 0.2 ^{a,b}	1.5 ± 0.3 ^{a}
5Su	4.9 ± 0.2 ^{b,c}	2.3 ± 0.2 ^{c,d}	2.1 ± 0.2 ^{c}
5Su+A	4.6 ± 0.2 ^{a,b}	2.8 ± 0.3 ^{e}	2.4 ± 0.2 ^{d}
10Su	4.5 ± 0.3 ^{a,b}	2.2 ± 0.2 ^{b,c}	1.9 ± 0.2 ^{b,c}
10Su+A	4.5 ± 0.2 ^{a,b}	2.5 ± 0.2 ^{d}	2.2 ± 0.1 ^{c,d}

APPENDIX D

TORTILLA CHIPS WITH SORGHUM BRAN

Table D-1. Moisture content (%) of tortillas for tortilla chip production. Values are means of 2 replicates, 3 observations each. Means in the same column followed by the same letter are not significantly different (α= 0.05). For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, and Su= Sumac bran.

Treatment	Moisture
Ctrl	44.1 ^{a}
5Bl	43.0 ^{a}
10Bl	43.7 ^{a}
5Su	43.6 ^{a}
10Su	43.2 ^{a}

Table D-2. Color of corn tortilla chips containing sorghum bran. L* indicates lightness, a* indicates hue on a green (-) to red (+) axis, and b* indicates hue on a blue (-) to yellow (+) axis. Values are means of 4 replicates, 3 observations each. Means in the same column followed by the same letter are not significantly different (α= 0.05). For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, and Su= Sumac bran.

	L*	a*	b*
Ctrl	60.8 ± 0.9 ^{e}	3.2 ± 0.6 ^{a}	25.1 ± 0.6 ^{e}
5Bl	40.7 ± 2.1 ^{b}	5.3 ± 0.1 ^{c}	7.1 ± 2.1 ^{b}
10Bl	37.1 ± 1.6 ^{a}	4.6 ± 0.2 ^{b}	4.6 ± 1.4 ^{a}
5Su	47.2 ± 2.7 ^{d}	7.3 ± 0.9 ^{d}	14.3 ± 2.1 ^{d}
10Su	42.5 ± 1.7 ^{c}	7.7 ± 0.5 ^{d}	11.0 ± 1.5 ^{c}

Table D-3. Phenol levels (mg GAE/g, db of defatted material) and ABTS antioxidant activity (μmol TE/g, db of defatted material) of tortilla chips containing sorghum bran. Values are means of 2 replicates, 3 observations each. Means in the same column followed by the same letter are not significantly different (α= 0.05). GAE= Gallic acid equivalents. TE= Trolox equivalents. For the acronym, the number indicates the percentage of bran added, Ctrl= Control, Bl= Black bran, and Su= Sumac bran.

Treatment	Phenols mg GAE/g	ABTS μmol TE/g
Ctrl	0.7 ± 0.1^{a}	6.6 ± 0.2^{a}
5Bl	1.4 ± 0.1^{b}	15.1 ± 0.5^{b}
10Bl	2.0 ± 0.2^{c}	23.0 ± 0.5^{d}
5Su	1.4 ± 0.1^{b}	16.0 ± 0.6^{c}
10Su	2.2 ± 0.1^{d}	25.4 ± 0.8^{e}

VITA

Guisselle Cedillo Sebastian received her Bachelor of Science degree in Food Engineering from Instituto Tecnológico y de Estudios Superiores de Monterrey in 2002. She entered the Food Science and Technology program at Texas A&M University in January 2003, and received her Master of Science degree in December 2005.

Ms. Cedillo may be reached at Plazuela Francisco Javier Clavijero #13, Fraccionamiento Animas, Xalapa, Veracruz, México, 91190. Her email address is guisselle@gmail.com